ECL-257

ENGINEERING CASE LIBRARY

STANDARD LADDER STANDARD

A look at the problem of developing standards which are nationally recognized and accepted. The portable metal ladder is used as an example.

C. O. Smith

Rose-Hulman Institute of Technology

Appreciation for permission to reprint is expressed to the ASTM (and the authors) for three papers from ASTM Standardization News for September 1978, the ASQC for a complete paper from the Proceedings of the Products Liability Prevention Conference, PLP-77E, and Dow Jones for an item from the Wall Street Journal of 11 August 1977.

STANDARD LADDER STANDARD

Part A

It is vital that all who are in the periphery of standardization be well-enough informed to judge for themselves its legitimacy, fairness, and openness; its ability to respond to change; its timeliness; and its social as well as economic value. Many questions arise: Does standardization result in sameness? Is it the enemy of style and fashion? Does it stand in the way of innovation? Is it a way for monster corporations to slow the growth of small businesses? Do standards put the consumer at the mercy of the manufacturer? Are standards merely the lowest common denominator? Must they be obeyed? How do they mesh with building codes and government regulations?

In addition, those at the periphery want to know how to gain access to the center of the process whenever it is in their own best interests to do so. Many are not even sure they know exactly what the words "standard" and "standardization" mean. So let us consider some simple definitions:

Standardization is the process of formulating and applying rules for an orderly approach to a specific activity for the benefit, and with the cooperation, of all concerned. The result of such a standardization effort merits being termed a standard when that effort is carried out by an organization whose scope and procedures embrace standardization.

"Standard" is not synonymous with specification, which is only one of five distinctly different types of standards. In ASTM, at least, "standard" is used as an adjective to describe the following:

Standard specifications are concise statements of requirements to be satisfied by a product, material, or process. It is desirable that the requirements be expressed numerically in terms of appropriate units together with their limits.

Standard test methods describe orderly procedures for determining a property or the performance of a material or product. The directions should include all of the essential details for achieving satisfactory precision both by the same operator in separate tests, or by operators in different laboratories.

Standard definitions create a common language for given areas of knowledge.

Standard practices are procedures or guides, often auxiliary to a test method or specification. Examples include sampling procedures, instructions for statistical calculations, evaluation of materials, and precautions about installation and operation of testing apparatus.

Standard classifications define systematic arrangements or division of materials and products into groups based on similar

characteristics, such as origin, composition, properties, or use.

A code is a set of rules of procedure and standards of materials designed to secure uniformity and protect the public interest in such matters as building construction, health, and safety.

There are several hundred organizations in the United States engaged in voluntary standards-making activities. They include branches of government, professional and technical societies, manufacturing and nonmanufacturing trade associations, public service and consumer groups, testing and inspection bodies. The great majority of standards that are in regular widespread use were developed and are kept current by a half-dozen organizations:

American Society of Heating, Refrigeration and Airconditioning Engineers (ASHRAE)
American Society of Mechanical Engineers (ASME)
American Society for Testing and Materials (ASTM)
Institute of Electrical and Electronic Engineers (IEEE)
National Fire Protection Association (NFPA)
Society of Automotive Engineers (SAE)
The largest of these, and the only one solely engaged in standardization, is ASTM.

This is a heterogeneous array of standards development organizations, resulting in a system which operates with a highly complicated, and sometimes overlapping, machinery. The standards produced by some elements of the machinery attain national and, (often) international acceptance as a result of the broad-based consensus procedures used to develop and approve them. Standards produced by different parts of the machinery assure varying kinds of consensus, and most of them satisfy quite well the needs of the sectors for which they were developed. Many of these standards are quite parochial in both development and use, but, despite this, they can be (and often are) fed into another part of the system for accreditation on their own, or for blending with other inputs, to become nationally accepted standards.

Each organization in the voluntary standards-making system has developed its own standards-making machinery through its experience and has tailored the machinery to fit its own scope and objectives.

Standards-writing committees are groups of experts and other interested persons who volunteer their time in real "coats-off, sleeves-up, pencils-out" draft development sessions. They are seeking the mutual benefit of all concerned through consensus.

In the ASTM process, the main committees, whose membership may number more than 600 persons, are made up of subcommittees and task groups. Subcommittees are comprised of people with expertise in

specific areas related to the work of the main committee. Task groups are ad hoc elements of subcommittees and they initiate draft standards and revisions. This is where the work actually begins. Task group leaders are usually appointed on a project basis, and volunteer task group members are sought.

Finally, there is the executive subcommittee whose responsibility it is to guide the activities of the main committee and subcommittees.

Together these groups function like this: When a task group prepares a draft document, it is reviewed by its parent subcommittee through balloting. If the document is approved by two-thirds of those returning ballots (a minimum of 60% of the voting interests must return ballots), the document proceeds to a main committee ballot. Here 90% of those returning ballots (again a 60% return is required), must approve the document. It then goes to a Society ballot, which means that each of ASTM's 28,000 members has an opportunity to request a copy of the proposed standard and comment on it. Of those who do comment on the proposal (usually several hundred, although a minimum of 50 ballots is all that is required), 90% must vote affirmatively.

All valid negative ballots must be considered by the originating subcommittee before a document can be published as a standard. To be valid, a negative vote must be accompanied by a written explanation of what the voter considers improper technical or procedural consideration. It is not uncommon for a negative comment to be judged persuasive. The document must then be rewritten by the subcommittee to incorporate the persuasive comments. If the negative comment is judged nonpersuasive, the objector is so notified, and the document proceeds to the next balloting level. This procedure applied each time a proposed standard is balloted.

Once the document has received approval via the Society ballot, it must still pass the ASTM Committee on Standards (a committee of the Board of Directors), which checks for compliance with procedural requirements and serves as a body to which the disposition of negative comments can be appealed. On approval by the Committee on Standards, the document is published as an ASTM standard.

Voluntary consensus standards are those developed through the voluntary participation of all interested parties. They are used voluntarily. Their use becomes mandatory only by legislation or when they are referenced by a government agency. Building codes, for example, reference hundreds of voluntary standards. Since building codes are the province of government, the referenced standards have the force of law and must be adhered to.

Mandatory standards also include some that are developed entirely by government agencies.

Voluntary standards and mandatory ones have coexisted since ancient times. It was the prerogative of kings and emperors to set and enforce standards for weights and measures, coinage, armaments and civil behavior. Standards for utility, function, and style, on the other hand, were the province of weavers, potters, and other artisans. Not by decree but by common consent, these workers devised informal standards that reflected social, cultural and economic values so accurately that they are now invaluable to archeologists. Today, only government can mandate standards that preserve and advance the multifaceted national interest, while the nongovernment sector (scientists, industrialists, consumers, ecologists and many others) voluntarily fashions the standards that quantitatively and objectively express technological progress, social values, public needs, and private wants.

We must not overlook the basic fact that people develop and use standards - not machines, computers, or hordes of monkeys chained to typewriters.

ASTM defines a consensus standard as a standard produced by a body selected, organized, and conducted in accordance with the procedural standards of due process. In standards-development practice a consensus is achieved when substantial agreement is reached by concerned interests according to the judgment of a duly appointed review authority.

ASTM believes consensus implies much more than the concept of a simple majority but not necessarily unanimity, which often can be achieved only by compromises that reduce the quality of the standard.

The American National Standards Institute

The American National Standards Institute (ANSI) is a voluntary federation that includes many of the more than 400 standards-writing bodies in the United States, as well as some other organizations and corporations. This nonprofit organization has four primary functions:

to be national coordinator for standardization in the United States

to approve as American National (consensus) Standards, those standards that have been submitted by Standards-developing organizations that are seeking or have already obtained public review

to serve as clearinghouse for information on American National Standards, and international standards of cooperating bodies of the International Organization for Standardization (ISO), and International Electrotechnical Commission (IEC)

to represent the standards position of the United States in international nontreaty organizations

ANSI is financed by its members' dues, by specified project support from industry and government, and by the sale of American National Standards, ISO and IEC documents, and other technical documents, and other technical publications.

More than 270 technical committees have been formed by ANSI during its 60 years to work on standards-development projects. Because ANSI may not, by its constitution, write standards, American National committees belong to the organizations of which they are comprised. Each has a Secretariat, usually an organization having a major interest in standards development in that field, which is responsible for administering the committee.

For further information, one might consult:

Cropper, W. V., "Standards and Standardization", CHEMTECH, Sept. 1979, pp 550-559

----- "The Voluntary Standards System of the United States of America", American Society for Testing and Materials, 1916 Race St., Philadelphia, PA 19103 (31 pg booklet) 1975

----- "Standardization Basics", ASTM

One arena in which standards are getting great attention in the 1970's and 1980's is in Products Liability litigation. Many products are placed in the marketplace bearing a label which says, in effect, that the product meets all the requirements established in a given standard. In a products liability lawsuit involving that product, the defendant manufacturer seeks to use the fact of conformance to a nationally recognized and accepted standard as a defense that he has indeed made a good product. The plaintiff often seeks to show that the standard is not really adequate.

In context, it must be recognized that product liability litigation (and all litigation) in the United States is conducted in an adversary mode. Although legal interpretation varies from one jurisdiction to another, it is generally true that failure to conform to a recognized and accepted standard leaves the manufacturer in a highly vulnerable position. Adherence to such a standard, however, is a weak defense as the plaintiff often convinces the jury (through use of expert witnesses) that a better or safer design was available at the time of manufacture which could have been used with minimal increase in cost of the product.

Even with the very brief statements above, it is obvious that development and/or review of a standard is not a simple matter. To give some insight, this case takes a look at the portable metal ladder for which both ANSI and the NFPA have had standards for many years.

Article from ASTM Standardization News, September 1978

The Ladder Standard: How Successful the Climb?

By Alvin S. Weinstein and John C. Frank

The following paper was presented at the ASTM symposium, "Technical Standards in Products Liability Litigation," which was held 5 May 1977 in Toronto by ASTM Committee E-40 on Technical Aspects of Products Liability Litigation. Discussions of the paper by Robert I. Werner, on behalf of the ANSI A14 Testing Task Force, and Samuel C. Cramer, on behalf of the Ground Ladder Subcommittee of the NFPA Fire Department Equipment Committee, follow the article. Weinstein is a professor in the Mechanical Engineering Department of Carnegie-Mellon University; Frank is a partner in Technical Engineering Consultants in Pittsburgh.

In November 1976, the Consumer Product Safety Commission published a denial of a petition to establish safety standards for aluminum and magnesium step and extension ladders [*1*]. In part, the *Federal Register* notice denying this petition states:

> The initial investigation by the Commission's staff into the risks associated with this product [ladders] disclosed that factors relating to approximately 50% of the current accidents reported through the National Electronic Injury Surveillance System (NEISS) could possibly be addressed by a standard. . . .
>
> At the present time, the American National Standards Institute (ANSI) A14 Committee, which has developed existing voluntary standards for ladders, is engaged in extensive testing and evaluation of ideas for more stringent voluntary standards for both wood and metal ladders. The areas which are being considered include the following:
>
> a. Label tests to measure adhesion and effective life.
> b. Extension ladder sliding tests.
> c. Friction tests for rungs and steps.
> d. Adequate safety factors.
> e. Dynamic and cyclic tests of ladders.
> f. Useful life and resistance to weathering.
> g. Corrosion.
> h. Suitable materials.
> i. The proper use and misuse of ladders.
> j. Human engineering factors.
> k. Stability.
> l. The effect of ladder accessories on ladder strength, human engineering factors, safety factors and stability.
>
> The areas which are being considered by ANSI for more stringent voluntary standards include the areas which are the subject of the petition.

Thus, since the CPSC believes that adequate voluntary standards will be adopted in 1977 which will sufficiently address the risks of injury connected with ladders, the commission denied the petition to develop a mandatory federal standard.

The fiscal year 1976 NEISS data [2] indicate that "Ladders and Stools" are 25th on a list of about 400 product categories and have an Age Adjusted Frequency-Severity Index (AFSI) of 3.353. For comparison, "Bicycles and Bicycle Equipment," first on the list, have an AFSI of 35.706, while "Power Lawnmowers" with an AFSI of 5.046 are ranked 17th. "Scaffolding," ranked 166th, has an AFSI of 0.215.

The relevant interpretation suggested by both the petition denial and the NEISS data is that there are recognized risks associated with ladder use that existing standards have not addressed. It is apparent that the areas listed above under consideration by ANSI for inclusion in a more stringent voluntary standard arise as a result of the gap between the performance requirements of the present standards and the hazards of use. In general, the performance requirements of present standards appear to focus on the *intended* use of the product rather than on the actual or *reasonably foreseeable* environment of product use. The standards do, however, appear to acknowledge some foreseeable uses different from intended uses that are *not* addressed by the recommended performance requirements.

This point is illustrated in the case study presented here, describing the collapse of a ladder that met existing standards but failed because the actual and foreseeable use was not addressed in formulating the tests required for ladder performance.

The Incident

In March 1973, during a training exercise conducted by several volunteer fire departments, an aluminum extension ladder on which three men were positioned collapsed, resulting in injuries to the men who fell to the ground.

The ladder, with its base on the ground and resting against a vertical wall, had been used for approximately $1\frac{1}{2}$ to 2 hours for various training exercises prior to its collapse. One of these exercises instructed the firemen in the proper procedures for passing one another on the ladder during ascent and descent. It was during such a passing exercise that the ladder collapse occurred.

It was estimated that this three-section, 10.7-m (35-ft) extension ladder was, at most, one or two rungs short of being fully extended and was at an angle of approximately 72 deg from the horizontal. Although the ladder was over four years old at the time of the collapse, the fire chief believed that the ladder had only been extended to the length used during this exercise about three times prior to the incident.

At the beginning of the passing exercise, the three men were positioned on the ladder with one man near the bottom, one at the middle, and the third man at the top. At times during the exercise, according to the fire chief providing the instruction, two men pass each other as one ascends and the other descends. This occurred twice during the exercise. The collapse occurred just after the second passing operation while the men were still moving on the ladder.

As a result of the collapse, the ladder was permanently deformed in both the lateral and transverse directions. The principal area of deformation was between the eighth and ninth rungs from the bot-

tom of the base section, just below the middle section overlap point. In addition to the deformation, there was cracking and separation of the two extrusions forming the side rail and loosening and loss of the rivets used for joining the two extrusions together, as well as loosening of the connection between the rungs and side rails.

This model of the extension ladder was originally marketed in 1956 and was discontinued in February 1974. The manufacturer indicated that the ladder in question was fabricated late in 1968 from 6061-T6 aluminum alloy, having a minimum yield strength of 241 255 kPa (35 000 psi) and a tensile strength of 261 934 kPa (38 000 psi) with a 10% elongation.

Standards of Performance

Unlike a consumer product, where the spectrum of foreseeable use patterns may require significant effort to describe, a ladder marketed for fire fighting has a well-prescribed pattern of uses. The passing exercise, in which the men were being instructed at the time of the collapse, is typical of the uses expected for a fire ladder. The *Oklahoma State Fire Manual*, which has been used as a source for fire-fighting procedures adopted throughout the country, describes this passing procedure [3]:

> When it is necessary for a person going up a ladder to pass a person coming down the same ladder, the one going up is responsible to give a signal. This signal should be given while the two men are at least ten feet apart. The person going up should move to the right side, and the person coming down should move to the left side. . . . In some instances, it may be advisable for the person coming down to stop on the left side until the pass is made.
>
> The number of men that may work from a ladder at one time must be limited to provide a margin of safety. The loading that may be recommended takes into consideration added weight that may be induced. A general rule-of-thumb is to space one man for every ten feet of ladder. This practice provides a safety factor so that two or *more* persons may be at the same point on the ladder during an emergency. [Emphasis added.]

Thus, one performance requirement for a fire ladder is quite clearly defined. Consequently, there is every expectation that ladders prescribed for fire fighting would be used in just this way at times during its life. The manufacturer of this ladder, in fact, has stated in an advertisement that "all [their] aluminum fire ladders are built specifically for Professional Fire Departments, and meet or surpass the stringent, demanding safety codes for fire-fighting equipment."

The safety code under which this ladder was manufactured is National Fire Protection Association (NFPA) No. 193, originally adopted in 1955, with Article 100, covering specifications for aluminum ground ladders, adopted in 1959. Section 101 of Article 100 states:

> The design and type of aluminum ladders used in fire service must, of necessity, be constructed to the most rigid standards. Conditions under which they are used call for ruggedness, strength and durability, along with ease of handling. Structural members of ladders shall be constructed of aluminum alloy having a minimum ultimate tensile strength of 35,000 psi. (Present aluminum alloys 6061-T6 and 6062-T6 satisfy the above requirements.) Ladders shall be designed for the loadings given in Section 132. Ladders shall be tested in accordance with Article 130.

The service conditions in Section 132, for which the prescribed tests are designated, are for "not more than three men on a solid beam extension ladder over 26 feet in length." This load limit is "based on the ladder supported at the top end against a building with the butt of the ladder at a distance not to exceed one-third the ladder length away from the building (approximately 55 degree angle), and preferably with the butt of the ladder placed one-fourth of the ladder length away from the building (approximately 65 degree angle). At angles less than these the load limit on the ladder will decrease accordingly." There appears to be an inconsistency here between the designated ladder angles and the relative distances of the ladder butt from the building. Using as the "ladder length," the distance along the side rails from the bottom to the support point for the upper portion of the ladder, the ladder angles would be 70.5 deg for the butt one-third the ladder length away from the building and 75.5 deg for the butt distance one-fourth the ladder length. There appears to be no interpretation of the requirement that can resolve the discrepancy.

The significant test in the NFPA standard which would relate to the ladder's service condition for carrying three men is contained in Section 135, "Testing Procedure for Single and Extension Ladders." The ladders are tested as simply supported beams in the horizontal position and extension ladders are tested by "treating each individual section as a single ladder." Each ladder section is incrementally loaded at its midpoint to 90.8 kg (200 lb). The load remains in place for five minutes and is then removed. The ladder section is permitted to recover for an additional five minutes. If the residual permanent deformation at the center is 0.318 cm ($\frac{1}{8}$ in.) or less, the ladder is considered safe. There are no tests prescribed which treat the ladder as a whole for performance requirements.

While the American National Standards Institute may presently be reexamining the requirements for their ladder standard, it is of value to compare requirements comparable to those of NFPA which are currently prescribed in ANSI A14.2—1972, "Safety Requirements for Portable Metal Ladders." In Section 3 of the ANSI standard, three duty ratings for ladders are prescribed: heavy duty (Type I), capable of supporting 113.5 kg (250 lb); medium duty (Type II), 102.15-kg (225-lb) load, and light duty (Type III), capable of supporting 90.8 kg (200 lb). The duty ratings, for extension ladders, are with the ladder at an angle of 75.5 deg and are said to be based on a safety factor of 4.

In order to establish a ladder's performance characteristics, Section 6.1.1 prescribes the horizontal bending test:

> The bending strength is measured by placing the ladder in a flat, horizontal position, supported 6 inches from the ends of the side rails. When testing single and extension ladders, the unit is opened to the required overlap.

After a one-minute preload at 75% of the test load, the full test load is placed at the center of the ladder. The test load is equal to the duty rating, that is, 90.8, 102.15, or 113.5 kg (200, 225, or 250 lb). Upon removal of the load, the permanent deformation at the center cannot exceed 1/1000 of the effective span of the side rails.

In prescribing the test loads for this horizontal bending test, the standard states: "This test is based on the rated load capacity of the ladder . . . with the ladder set at 75-$\frac{1}{2}$° to the ground. With the rated load of the ladder on the center rung, the component of this weight at right angles to the ladder will be equal to one-quarter of the test load. The test load incorporates the required safety factor of 4 on horizontal bending."

It is of interest to compare and contrast the requirements of these two standards (NFPA and ANSI) for the crucial horizontal bending tests:

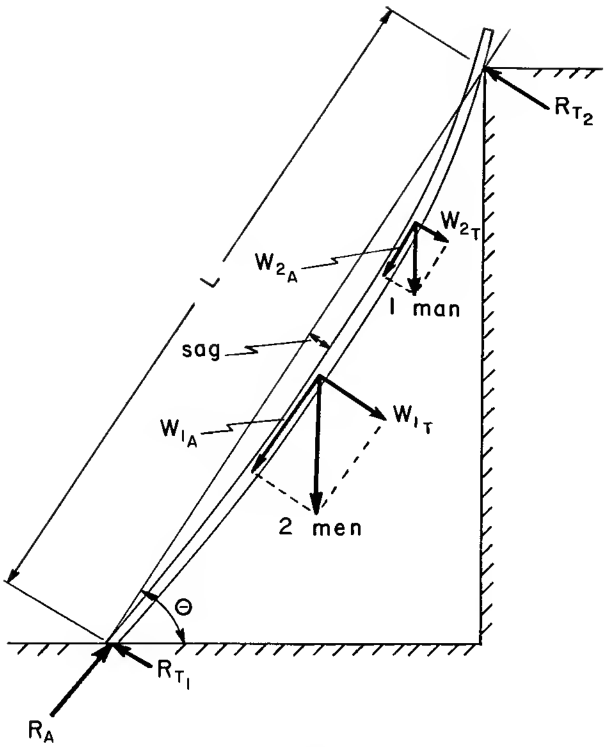

FIG. 1—*Presumed ladder loading at failure.*

• **Test Loads**—ANSI indicates three duty ratings, with corresponding test loads of 90.8, 102.15, and 113.5 kg (200, 225, and 250 lb). NFPA prescribes a single test load of 90.8 kg (200 lb). Relative to the ANSI standard, fire ladders would be classified as *light duty*, Type I, based upon the required test load.

• **Test Methods**—ANSI prescribes the test load to be applied to a *fully extended* extension ladder. NFPA indicates that each section of an extension ladder is to be tested separately with the test load.

• **Test Requirements**—ANSI limits allowable permanent deformation to 1/1000 of the ladder span. NFPA limits permanent deformation to 0.318 cm (1/8 in.), regardless of length. Thus, for ladders or ladder sections longer than 3.17 m (10.4 ft), the NFPA requirement is more stringent; that is, it requires less permanent deflection. For test lengths less than 3.17 m (10.4 ft) the ANSI standard would be more stringent.

• **Performance Implications**—ANSI indicates that "portable metal ladders are designed as a one-man working ladder including any material supported by the ladder." However, it is noted in Section A3.19 of the ANSI standard that ladder jacks and stages or planks can be used on the medium and heavy duty ladders. The bending test, however, is described a insuring a safety factor of 4 for the ladder, presumably under all conditions of use. NFPA notes that extension ladders of over 7.92 m (26 ft) in length can have three men on the ladder and it is obviously implied that the horizontal bending test should indicate the safety of the ladder under this use condition. There is no indication of an expected safety factor.

Apart from the fact that NFPA tests each ladder section separately while ANSI extends the ladder fully for testing, there appears to be a serious contradiction in the implied performance that the horizontal bending test, using comparable loads in both tests, is to ensure. The ANSI standard indicates a one-person use, while NFPA acknowledges that there can be three persons on the ladder; yet, both can use test loads of 90.8 kg (200 lb).

The ANSI standard, however, acknowledges the use of ladder jacks with scaffolding for the medium and heavy duty ladders. It is not difficult, then, to imagine that when used in conjunction with scaffolding, an extension ladder could easily have the equivalent of a three-person load, as is recognized by the NFPA standard. Perhaps, then, the only intrinsic difference in the implied performance tests is the modest increase in the horizontal test load from 90.8 kg (200 lb) to 102.15 kg (225 lb) or 113.5 kg (250 lb) that would ensure consistency between the requirements of the standards. Or, stated another way, perhaps the 22.7-kg (50-lb) maximum test load difference may *not* elicit any significant distinction in performance requirements, thus implying equivalence of the two standards in this respect. In either event, however, it is reasonable to expect that the critical performance requirement, the horizontal bending test, should ensure adequate ladder performance with the equivalent of three persons in the center of a ladder, a foreseeable use pattern.

The Ladder Failure

Within the context of what both standards appear to imply concerning actual ladder use (that is, three persons on a ladder or the use of ladder jacks and scaffolding), as well as the tests prescribed for ensuring sufficiency of performance, consider the findings of the investigation of the fire ladder involved in this incident.

The permanent deformation in the plane of the ladder as well as normal to the ladder plane was indicative of a classic buckling failure arising from plastic instability. There were no indications that any detectable damage to the ladder had occurred prior to this failure. Specimens were taken from the side rails of the failed base section and the undeformed top section. Chemical analyses revealed that the material composition was within the limits for the 6061 aluminum alloy.

The tensile tests, however, showed significant variation from the prescribed minimum yield and tensile strengths. In the base section, the 0.2% offset yield strength averaged 186 111 kPa (27 100 psi), about 23% lower than the 241 255 kPa (35 000 psi) minimum for 6061-T6. The tensile strength averaged approximately 7% less than the 261 934 kPa (38 000 psi) prescribed for 6061-T6. The top or fly section specimens showed similar deviations. The yield strength was 28% less and the tensile strength was 9% lower than the prescribed values.

These data indicated that while the side rail material was, undoubtedly, the appropriate aluminum alloy, 6061, the temper was, most probably, not the T-6 specified but may have been T-4. Actual physical property values that are lower than those specified for a material may be classified as a manufacturing flaw. However, lower property values need not render a product defective unless, as a result of the flawed properties, the product cannot meet the

expected standards for its performance.

In this instance the ladder was being properly used by three men during a passing procedure, which is a typical performance requirement for fire ladders. While the NFPA standard does not mention a safety factor, the similarity of the horizontal bend tests, including the test loads, to that of the ANSI standard, suggests that the explicitly mentioned safety factor of 4 in the ANSI standard is equally applicable to the NFPA standard.

If this assumption is valid, then the fact that the yield strength of the base section side rail material was 23% lower than that specified should *not* have significantly eroded the ladder's capability to meet the performance expected during the passing exercise. Yet, the ladder collapsed, and without evidence of any structural weakening prior to this incident that might have precipitated failure at a lower yield stress.

Thus the question raised by this factual situation is, To what extent do the critical horizontal bending performance tests in the standards give adequate assurance of "safety under normal conditions of usage" [4]? That is, is there in actuality a safety factor of 4 implicit in the horizontal bend tests of both standards, relative to the expected environment of ladder use?

To bring this question into focus, consider the approximate loading on the fire ladder at the time of collapse. As shown in Figure 1, the vector at the middle of the ladder represents the weight of the two men passing at that point. The vector approximately three-fourths of the way to the top represents the third man. There is, of course, the distributed weight of the ladder as well as the weight of the men which must be resisted by the external reactions.

The ladder ground reaction (see Figure 1) can be resolved into two components, the axial reaction R_A and the transverse reaction R_{T_1}. Since the building's support for the ladder cannot sustain a significant axial reaction, only the transverse reaction, R_{T_2}, is shown.

Since ladders are not infinitely stiff in bending, all ladders will deflect when loaded, as suggested by the sag indicated in Figure I. It is this deflection under load, however, that can significantly and seriously increase the side rail bending stress as a result of the axial loading on the ladder under normal use conditions.

This effect of the axial component of the ground reaction can be better illustrated if the ladder is considered rotated to the horizontal position, but maintaining the actual loadings. In Figure 2 the loadings of Figure 1 are shown only by their components, now in the horizontal and vertical directions. If it is imagined that the vertical loadings W_{1T} and W_{2T} are placed on the ladder first without the horizontal components, then the ladder will deflect an amount, say δ' (Figure 2). Superimposing the horizontal reactions W_{1A} and W_{2A} together with the ground reaction R_A now creates an additional bending moment in the side rail whose magnitude is on the order of $R_A \times \delta'$. This additional bending moment causes the deflection of the ladder to increase to a new equilibrium value, shown as δ. As a result, the bending stress in the side rails increases beyond that which would exist if only the normal loads, W_{1T} and W_{2T}, acted alone.

It is evident that the extent to which the axial loadings increase the bending stress is a function of the span length L and the ladder stiffness, as determined by its moment of inertia I. The longer the span and the smaller the stiffness, the more significant is the effect of the axial loads on the bending stress. An estimate of the magnitude of this effect was obtained by developing an analysis of a simple beam under the loading conditions shown in Figure 3. The pertinent elements, as well as the results of this analysis, are given in the Appendix.

The critical factor that determines the effect of the axial load P (Figure 3) on the maximum bending stress in the ladder is termed the compressive flexibility factor, u, and is defined by:

$$u = L/2\sqrt{P/EI}$$

where

L = span length of the fully extended ladder, cm,
P = axial component of the load on the ladder, kg,
E = modulus of elasticity of the ladder material, kPa, and
I = combined moment of inertia of side rails for out of plane bending, cm^4.

To illustrate the effect of the compressive flexibility factor, Figure 4 shows the decrease in "safety factor" as u increases. The safety factor in Figure 4 is defined as the ratio of the maximum side rail stress generated in the horizontal test, required by the standards, to the side rail stress that would be generated if the *same* load as in the bend test were vertically applied to a ladder erected at angles of 55 and 75.5 deg.

It is apparent that the safety factor of 4, as indicated in the ANSI standard, only exists for values of u less than about 0.2 when the ladder is erected at a 75.5-deg angle and decreases to 1.0 when the lad-

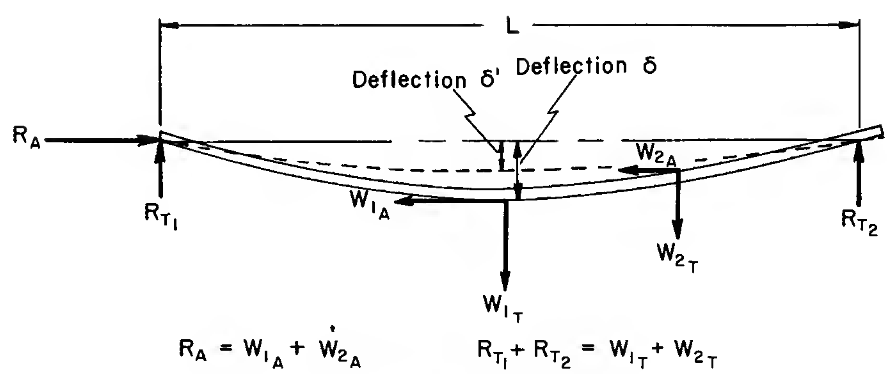

FIG. 2—*Ladder loading for analysis.*

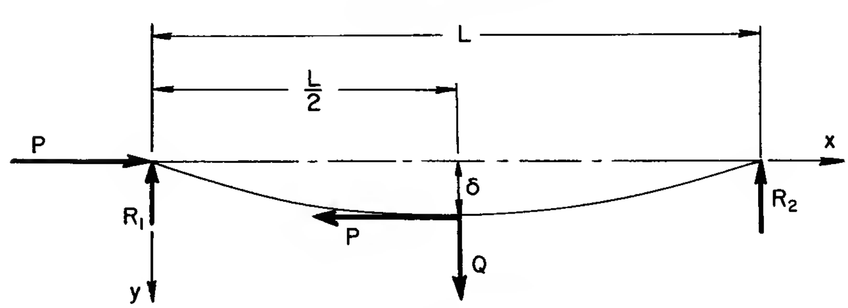

FIG. 3—*Model for examining ladder flexibility.*

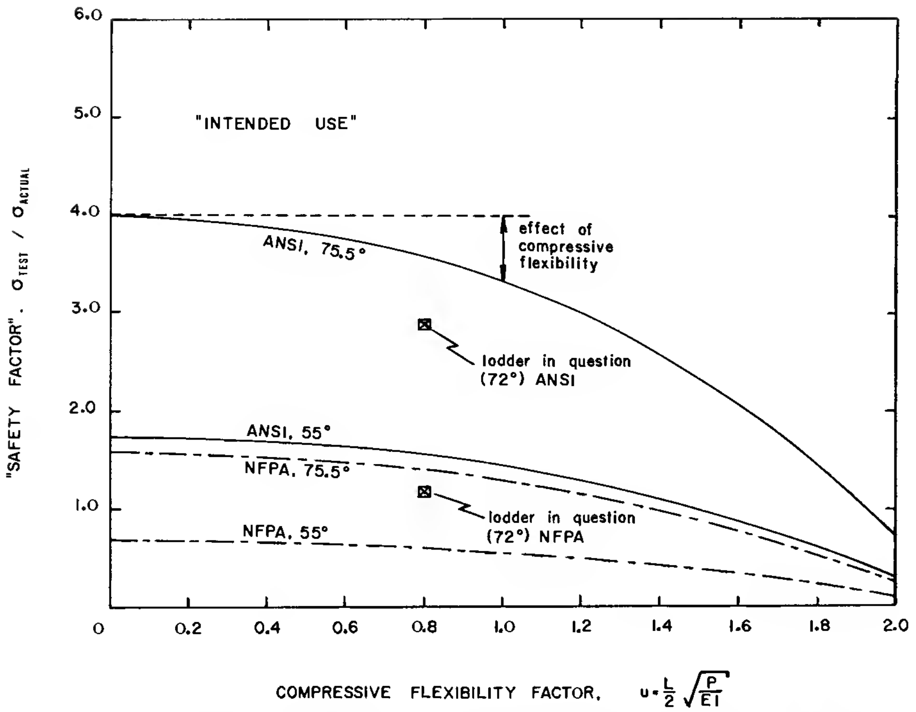

FIG. 4—*Ladder "safety factor" as a function of compressive flexibility based on "intended use."*

der's compressive flexibility factor is about 1.95. If the ladder is erected, instead, at an angle of 55 deg (which is presumably permissible in the NFPA standard, and is considered reasonably foreseeable for any ladder), the maximum safety factor for the ANSI standard never exceeds about 1.74 (for an infinitely stiff ladder, $u = 0$) and decreases continually as the ladder's flexibility increases.

The implicit safety factor from the NFPA standard is considerably less than that for the ANSI standard since the NFPA standard requires that the horizontal bending test be performed separately for each section of an extension ladder, rather than on the ladder fully extended. It has been assumed, for the NFPA curves in Figure 4, that a fully extended ladder is about 2.5 times longer than the average length of each section of a three-section ladder.

As a reference, the compressive flexibility factor for the fire ladder in question is about 0.8 when the ladder is erected at 72 deg, assuming a ladder load W of 90.8 kg (200 lb), a span length L of 10.67 m (35 ft), the actual total side rail I of 54.94 cm^4 (1.32 in.^{4}), and $E = 68.93 \times 10^6$ kPa (10×10^6 psi). Thus, in Figure 4, relative to the ANSI standard, the fire ladder had a safety factor of about 2.9, while based upon the NFPA standard, the safety factor was about 1.2.

Whatever concern may be evoked for the values of these safety factors, they only represent the effect of comparing the ladder stresses when the *test* load of the standard is placed on the ladder in the erected position. In a sense, then, the curves of Figure 4 indicate the stress ratios for the "intended use" of the ladder, that is, when the maximum load on the ladder *in use* does not exceed the test load prescribed by the standard.

However, the earlier discussion has indicated that the *foreseeable* conditions of ladder use would argue for an actual ladder load of at least *three* times the test load prescribed by either the NFPA or ANSI standard. To examine the effect of this performance requirement, the bending stress in the erected ladder, subjected to a vertical load three times the standard's test value, is compared with that developed in the ladder under the prescribed horizontal bending test.

Figure 5 gives the ratio of the actual stress, σ_A (erected ladder, carrying three times the bend test load), to the stress developed in the prescribed bend test, σ_T. For the ANSI standard, with the ladder at 75.5 deg, the actual stress is 75% of that developed in the bend test, if the ladder is infinitely stiff ($u = 0$). Once u, the compressive flexibility factor, exceeds about 1.2, however, the actual stress exceeds the bend test stress. At a ladder angle of 55 deg, however, the actual stress is 1.72 times that in the bend test for $u = 0$ and increases rapidly as the ladder increases in flexibility.

The same behavior is evidenced for the comparison with the NFPA standard in Figure 5, except that the stress ratios are all 2.5 times larger than those for the ANSI standard. This multiplication factor is the result of the NFPA standard requiring that each ladder section be tested separately rather than testing the fully extended ladder as in the ANSI standard.

For the fire ladder, the compressive flexibility factor u has increased to approximately 1.38, since the axial load P is now three times larger than the value in Figure 4. This results in stress ratios of 1.4 and 3.5 for the ANSI and NFPA standards, respectively, with the ladder at an angle of 72 deg. But these stress ratios can only be of concern in ladder performance if the maximum bending stress in the ladder side rails resulting from the horizontal bending test is a relatively large fraction of the material yield stress.

The extreme fiber stress for this 10.67-m (35-ft) ladder, if tested at full length with a 90.8-kg (200-lb) central load (ANSI requirement), is $\sigma_T = 157\,850$ kPa (22 900 psi). If the 90.8-kg (200-lb) load is applied to a single 4.27-m (14-ft) section of this ladder (NFPA requirement), the test stress is $\sigma_T = 63\,140$ kPa (9 160 psi). However, the *actual* stress in the side rails for a 272.4-kg (600-lb) load when the ladder is at 72 deg is found by multiplying these σ_T stresses by the appropriate stress ratios listed above and shown in Figure 5. Thus,

$$\sigma_{A_{\text{ANSI}}} = 157\,850 \times 1.4 = 220\,990 \text{ kPa}$$
$$(22\,900 \times 1.4 = 32\,100 \text{ psi})$$

$$\sigma_{A_{\text{NFPA}}} = 63\,140 \times 3.5 = 220\,990 \text{ kPa}$$
$$(9\,160 \times 3.5 = 32\,100 \text{ psi})$$

(The actual stress in the ladder during use must, of course, be independent of which standard is used to generate the value. The differences in the bend test stress values and multiplication factors simply reflect the fact that in the ANSI test the ladder is at full extension, while the NFPA standard tests only one section of the ladder.)

It is now readily apparent why the fire ladder failed during the three-man passing exercise. The fiber stress of about 220 990 kPa (32 100 psi) exceeded the material yield stress of about 186 111 kPa (27 000 psi). Thus, local yielding undoubtedly took place in the side rails, leaving the ladder in an unstable configuration with final buck-

ling collapse imminent and unpredictable.

This conclusion has been drawn based upon a loading that concentrated 272.4 kg (600 lb) (approximately the weight of the three men) at the center of the ladder. The actual loading at the time of collapse was most probably two men at or near the midpoint of the ladder with the third man above them and would result in a stress somewhat lower than 220 990 kPa (32 100 psi). It must be remembered, however, that the calculated stress level is based upon a static load, while, in actuality, the dynamic loads imposed on the ladder as the men move would unquestionably result in a stress level significantly greater than the 220 990 kPa (32 100 psi) calculated for this model. Thus, the assumed 272.4-kg (600-lb) static load at the ladder midpoint may *not,* in fact, be a conservative estimate of the foreseeable use condition.

It should be noted, too, that even had the side rail contained material with the specified yield strength of 241 255 kPa (35 000 psi), the readily expected lower bound stress of about 220 576 kPa (32 000 psi) during foreseeable use would give an inadequate margin of safety, well below that of accepted engineering practice. Hence, this ladder collapsed as a result of substandard side rail material combined with a basic side rail design that gave an inadequate margin of safety.

Standards for Performance

Earlier, the question was posed: Is there, in actuality, a safety factor of 4 implicit in the horizontal bend tests of the standards, relative to the *expected* environment of ladder use? For the foreseeable use pattern illustrated in Figure 5, the answer, of course, is a disturbing *no.* Based upon the ANSI standard with the ladder at 75.5 deg, an infinitely stiff ladder ($u = 0$) would, at best, have a submarginal safety factor of 1.33 for an actual load three times larger than the test load. This safety factor decreases for increasing ladder flexibility and would have a value of 0.5 if the ladder was designed with a compressive flexibility of 1.8 (Figure 5).

Yet, the fire ladder in question would have easily met the acceptance test for horizontal bending in both standards since the stresses induced in the tests (157 850 kPa (22 900 psi) and 63 140 kPa (9 160 psi)) were below even the submarginal yield strength of the side rails. The ladder would not have exhibited any permanent deformation as a result of either standard's horizontal bending test, and would therefore have been considered to be acceptable, when checked either by the manufacturer or by the user after field use.

It is apparent, then, that both the ANSI and NFPA ladder standards seriously underestimate reasonably foreseeable use patterns as well as the effect of actual ladder geometry, that is, compressive flexibility, on the ladder performance. Figure 4 demonstrates that, considering only "intended use" behavior, there can be significant erosion of the "safety factor" for relatively flexible ladders. This has not been acknowledged in either standard.

It is submitted that a performance requirement based solely on the horizontal bending test as presently conceived in the standards is totally inadequate, certainly for field checking during a ladder's lifetime and, more importantly, inadequate as a requirement for certification by a manufacturer.

In developing a new standard for ladders, it becomes clear that there must be a separation between requirements for ladder design and those developed for regular field checks during actual use. For the designer, the standard must indicate limits on the compressive flexibility factor u, based upon foreseeable use patterns. The standard must acknowledge that ladder angles can be anticipated to be significantly less than 75.5 deg, or require a means for the user to set the ladder, easily and accurately, at the appropriate angle.

For the user, a field test should be prescribed that will readily demonstrate that the ladder retains an adequate margin of safety, based upon a foreseeable use environment. The standard must address the issues of design and field performance clearly, recognizing the important considerations of both with appropriate prescriptions for each.

Conclusion

The intent of this case study was to illustrate, in some depth, only one critical issue in ladder performance, that of behavior in out-of-plane bending. There are a number of other equally important issues, identified in the introduction, which have been acknowledged by the ANSI A14 committee and presumably will be considered in

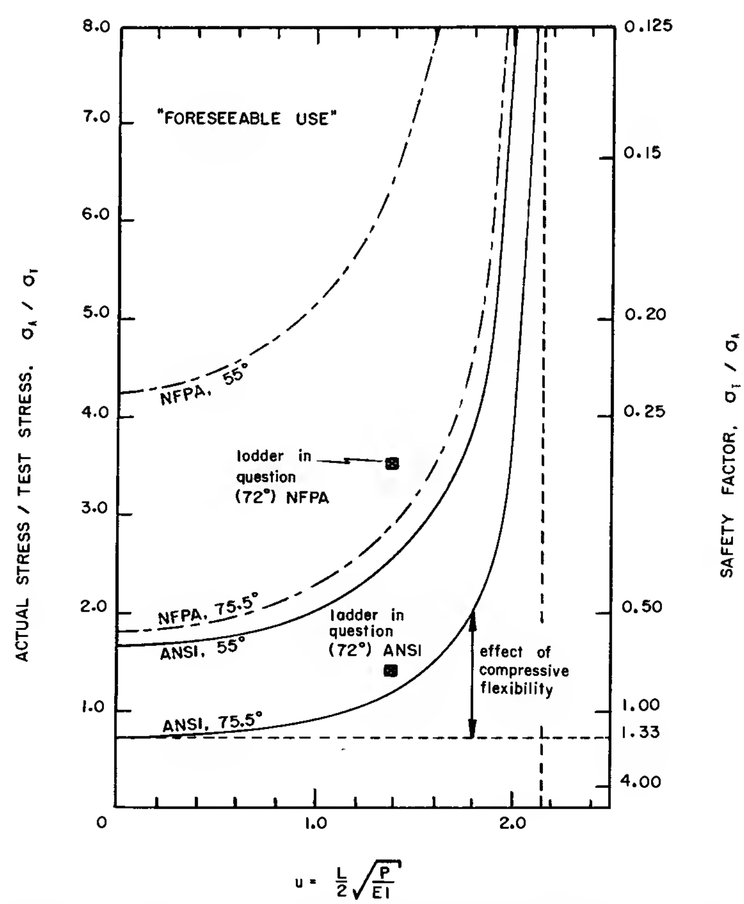

FIG. 5—*Stress ratio and safety factor versus compressive flexibility for ladder loads three times test load.*

the deliberations for a modified standard.

It should be apparent from the considerations developed here that each of these issues must be examined in depth and with care to ensure that the balance between an unreasonably dangerous product and one that is reasonably safe is struck upon the foundation of a realistic assessment of both users and the environment of product use.

REFERENCES

[1] "Aluminum and Magnesium Step and Extension Ladders, Denial of Petition," *Federal Register*, 41 FR 52100, Washington, D.C., 26 Nov. 1976.

[2] "Consumer Product Hazard Index," Consumer Product Safety Commission, Washington, D.C., 7 Feb. 1977.

[3] *Oklahoma State Fire Manual*, Section 17, "Safety Measures for Climbing," Oklahoma State University, Stillwater, Okla., pp. 29, 30.

[4] "Safety Requirements for Portable Metal Ladders," ANSI A14.2—1972, American National Standards Institute, New York, 1972, Section 1.1.

APPENDIX—Simple Beam Analysis of a Ladder Under Axial Loading

For the simply supported beam shown in Figure 3, force and moment equilibrium in the deflected position gives for the vertical reactions, R_1 and R_2:

$$R_1 = \left(\frac{Q}{2} - \frac{P\delta}{L}\right) \qquad R_2 = \left(\frac{Q}{2} + \frac{P\delta}{L}\right)$$

where δ is the center deflection under the load Q and is unknown.

The deflection equations for the beam sections to the left and right of Q are:

$$\text{Left side:}\quad EI\frac{d^2y}{dx^2} = -R_1x - Py$$

$$\text{Right side:}\quad EI\frac{d^2y}{dx^2} = -R_2(L - x)$$

These may be solved, to yield, for the left side:

$$y = A\cos kx + B\sin kx - \frac{R_1}{P}x \tag{1}$$

where $k^2 = P/EI$, and for the right side:

$$y = \frac{-R_2}{EI}\left(\frac{Lx^2}{2} - \frac{x^3}{6}\right) + Cx + D \tag{2}$$

The boundary conditions are:

$$\text{At } x = 0, L \quad y = 0$$

$$\left.\frac{dy}{dx}\right|_{x = \frac{L}{2}\text{ (left)}} = \left.\frac{dy}{dx}\right|_{x = \frac{L}{2}\text{ (right)}}$$

After having found the constants of integration from these boundary conditions, the unknown center deflection δ can be found from either the left side or right side equation, using the condition

$$y = \delta \ @\ x = \frac{L}{2}$$

The result is:

$$\delta = \frac{QL^3}{48EI}\left\{\frac{2[u^2\tan u + 3(\tan u - u)]}{u^2\left(u + 3\tan u - \frac{u^2}{3}\tan u\right)}\right\} \tag{3}$$

where $u = (L/2)\sqrt{P/EI}$, the compressive flexibility factor. The bending moment at the center, under the vertical load Q, is obtained from:

$$M_A = R_2\frac{L}{2} = \left(\frac{Q}{2} + \frac{P\delta}{L}\right)\frac{L}{2}$$

Substituting for δ from Equation 3 gives:

$$M_A = \frac{QL}{4}\left[\frac{4\tan u}{u + 3\tan u - \frac{u^2}{3}\tan u}\right] \tag{4}$$

For a simply supported horizontal beam of length l with a vertical center load of W, the maximum bending moment (under the load) is:

$$M_T = Wl/4$$

Since the outer fiber stress for any simple beam is $\sigma = Mc/I$, then the ratio of the bending moments in Equations 4 and 5 is equivalent to the stress ratio, since the same beam is being compared for two different loading conditions. Using the notation $\sigma_A \propto M_A$ (the maximum actual fiber stress in the ladder under combined axial and normal loading) and $\sigma_T \propto M_T$ (the maximum fiber stress developed in the ladder in a horizontal bending test per the standards), then:

$$\frac{\sigma_T}{\sigma_A} = \frac{M_T}{M_A} = \frac{Wl}{QL}\left[\frac{u + 3\tan u - \frac{u^2}{3}\tan u}{4\tan u}\right] \tag{6}$$

and

$$\frac{\sigma_A}{\sigma_T} = \frac{M_A}{M_T} = \frac{QL}{Wl}\left[\frac{4\tan u}{u + 3\tan u - \frac{u^2}{3}\tan u}\right] \tag{7}$$

where $u = (L/2)\sqrt{P/EI}$, the compressive flexibility factor.

Equation 6 was used to develop Figure 4 and Equation 7 led to Figure 5. In Figure 4, the comparison was made for a ladder erected at angle θ, subjected to a vertical load equal to the load W in the horizontal bending test. Thus, in Equation 6:

$$Q = W\cos\theta$$

and, if needed,

$$P = W\sin\theta$$

where θ is the ladder angle measured from the horizontal (Figure 1) and for which the values of 55 and 75.5 deg were chosen.

In the ANSI standard, the horizontal bending test is conducted with the ladder fully extended, hence $l = L$ in Equation 6. Since the NFPA standard tests each section separately, then l in Equation 6 is the length of only one section. In order to perform the calculations, it has been assumed that for a three-section ladder the ratio of the length of the fully extended ladder to the length of one section is 2.5, that is, $L/l = 2.5$.

To develop Figure 5, it has been assumed that foreseeable use would argue for an actual ladder load of at least three times the test load. Hence in Equation 7:

$$Q = 3W\cos\theta$$
$$P = 3W\sin\theta$$

Again $l = L$ for the curves labeled ANSI and $L/l = 2.5$ for the NFPA curves.

You have had an opportunity to review the paper by Weinstein and Frank published in the ASTM Standardization News. Reference was made to both NFPA and ANSI standards. How would you respond if you were elected to represent the appropriate committee from either ANSI or NFPA?

STANDARD LADDER STANDARD

Part B

Discussion of "The Ladder Standard: How Successful the Climb?"

By Robert I. Werner

The following discussion of the paper by Alvin S. Weinstein and John C. Frank, "The Ladder Standard: How Successful the Climb?," was written by Robert I. Werner, of R. D. Werner Co., Inc., on behalf of the Testing Task Force of ANSI Committee A14 on Construction, Care, and Use of Ladders.

The paper by Weinstein and Frank, "The Ladder Standard: How Successful the Climb?," reviewed certain problems that the ANSI ladder standards committee has attempted to address over the years. Discussion with the ANSI A14 Committee on Construction, Care, and Use of Ladders, its Testing Task Force, or the NFPA Committee on Fire Department Equipment would have indicated the depth of research and testing that has occurred in the past and that serves as the foundation for the current standards, as well as the ongoing development work that will become part of the next standards revisions. Further, a literature survey would have revealed the basis for most of the present requirements and identified the trade-offs made in developing these standards criteria.

An attempt will be made to provide additional insight into the areas discussed by the authors and, it is hoped, provide the basis for the correction of certain misconceptions.

The Range of Problems Proposed by the Paper

The authors introduced a number of different subjects that were intermingled in their paper and create difficulty in providing a simple reply. Some of these topics include:

- In the comparison of ANSI A14.2-1972 [1] with NFPA 1931-1975 [2],[1] the only references to NFPA 193 identified it as being adopted in 1955 with the Aluminum Ground Ladder Specification being adopted in 1959. There was little information to assist the reader in appreciating that ANSI A14.2 is intended to be a performance document, while NFPA 193 is designed to cover the "Use, Maintenance, and Testing of Ground Ladders," and is intended for in-service applications.
- A specific incident or accident was discussed covering a fire ladder and training exercise.
- The authors introduced concepts of the intended use of product versus the actual—or reasonably foreseeable—environment of product use.
- The authors established certain foreseeable uses based upon information in the NFPA document, and then proceeded to extend these to portable metal ladders. In their analysis they addressed a portion of the problem in terms of the loads that a ladder rail might "see," but did not explore certain of the other aspects of the man-ladder-environment interfaces that are critical from a safety viewpoint. In addition, the use of highly trained fire fighters provides an opportunity in product design that may not be available to a portable ladder designer, where the product is used by the general populace.
- The authors evaluated the horizontal bending test and worked from a number of assumptions that are not necessarily valid. In all cases the horizontal bending test is not the "crucial" test that determines whether a given design will meet the requirements of ANSI A14.2. The use of ladder jacks and stages or planks does not "easily" permit the equivalent of a three-person load to be applied to an extension ladder.

Timeliness of Standards

The authors employed ANSI A14.2-1972, which is the latest issue. Unfortunately, relative to NFPA 193, the actual issue employed in their evaluation was not identified. The various issues from 1958 through 1972 are fairly comparable in the areas of concern in the paper.

The 1975 revision split apart ground ladders from metal aerial and elevating platform products. The ground ladder specification has now become NFPA 1931-1975. There are very significant differences between this issue and the requirements as discussed in the paper. Specifically, the 1975 edition has adopted—for the in-service testing requirements—the performance tests for the Type I products in ANSI A14.2-1972. Consequently, much of the comparative analysis in the paper is thereby obsolete.

NFPA 193

It appears that NFPA 193-1972, or an earlier edition, was used by the authors in developing their presentation. ANSI Committee A14 has pointed out to NFPA that the test load requirements in NFPA 1931-1975 are low relative to fire ladder requirements. However, the decision as to what level will be specified is outside the control of ANSI Committee A14.

ANSI A14.2-1972 is a performance standard. It establishes requirements the manufacturer is to meet in the design of his product. In contrast, NFPA 1931-1975 test requirements are intended for use as an in-service testing procedure. The methods

[1] NFPA 193, "Standard on Fire Department Ladder, Ground and Aerial," was adopted in 1955. A complete revision of NFPA 193 was adopted in 1972 and is identified as NFPA 193-1972. During 1974 and 1975, studies resulted in a recommendation to develop separate documents on ground ladders and aerial ladders. During the drafting and approval stages, the ground ladder document had been identified as NFPA 193A-1975. Due to a renumbering of Fire Service Standards, the new "Standard on Fire Department Ground Ladders" was approved in 1975 and is identified as NFPA 1931. Throughout this discussion this particular edition will be identified as NFPA 1931-1975.

were designed to be employed in a fire house. Reference *3* states:

> The following outlined tests do not introduce loads or stresses that will contribute to a failure of a ladder, for they are well within safe stress limits.

The development of tests must consider the purpose for which the test is intended and the disposition of the tested product. An in-service test should permit continued use of the product if the product is deemed serviceable. The stress level or amount of strain imposed on the structure must be low enough so as to avoid damage to an otherwise acceptable product. Consequently, any in-service test will be less rigorous than the design verification tests. In the latter case, one expects the product to be destroyed subsequent to testing. This is a serious consideration in ladder standards as a person performing a test may unknowingly damage the product and this could lead to injury.

Prior to 1975, NFPA 193 employed what has been termed a "recovery test" method. This has been described in NBS Report 10-474 [*4*] and NBS Technical Note 833 [*5*]. Technical Note 833 recommended a series of improvements. The 1975 revision incorporated many of these recommendations. As the authors recognized, the angles of 55 and 65 deg were incorrect, and should have been 70.7 and 75.5 deg, respectively. A slope of 1:3 is equivalent to 70.7 deg and 1:4 to 75.5 deg. The latter slope is equivalent to what various writers term the "quarter-length rule."

Many of the improvements in the NFPA 1931-1975 included:

- Specifying metal alloys with a yield strength minimum of 241 255 kPa (35 000 psi) and an ultimate tensile strength of 261 934 kPa (38 000 psi).
- Defining the overlap of the ladders.
- Establishing maximum ladder loadings in terms of a weight requirement rather than a more generalized manpower requirement. On an extension ladder of from 8.2 to 13.7 m (27 to 45 ft), the 1975 edition stipulated a maximum ladder loading of 272.2 kg (600 lb), while in the earlier editions they talked of not over three persons on a solid beam ladder over 7.9 m (26 ft). A14 suggested inclusion of a safety factor for design verification purposes, or a required design test load to Table 8-1.3. The loadings stipulated in the table are really maximum working loads or the duty rating of the ladder, rather than the maximum test load.
- NFPA substituted many performance requirements of A14.2-1972 in their 1975 edition. For example, the horizontal bending test is now the requirement of NFPA 1931-1975.
- Unfortunately, NFPA 193 does not specify a minimum requirement that ladders meet for design verification purposes. The user, purchaser, or designer must go to other sources for this detail. The information *is* available in the *Fire Chief's Handbook* [*6*] which stipulates—for a 10.7-m (35-ft) extension ladder—a total of 476.3 kg (1050 lb) be applied with the ladder set at approximately 78 deg; 79.4 kg (175 lb) would be placed at each specified rung—the 7th, 12th, 16th, 21st, 25th, and 30th. Other sources include Underwriters' Laboratories of Canada [*7*], whose horizontal bending test has a load requirement of 340.1 kg (750 lb).

Comments Regarding "Standards of Performance"

Using A14.2-1972, a ladder could not be classified as "light duty, Type I." A ladder would either be intended for light duty service with a duty rating load of 90.7 kg (200 lb) and be a Type III, or else could be classified for heavy duty service with a duty rating load of 113.4 kg (250 lb) and be termed a Type I product.

The latest ANSI and NFPA ladder standards require the horizontal test method be employed utilizing fully extended ladder. As the NBS studies stated [*4,5*] the ANSI horizontal bending test requirement is more stringent than the recovery test method previously employed in NFPA 193.

The horizontal bending test uses a maximum permanent set limit. The difference in spans required in the two tests causes bending moments in the ANSI test to be higher as well as the resulting strain and stress levels. NFPA 1931-1975, while it incorporates the ANSI horizontal bending test requirement, is still an in-service type of test because the load levels stipulated are modest and not intended to overload the ladder.

ANSI A14.2-1972 stipulates that "portable metal ladders are designed as a one-man working ladder." The NFPA standard stipulates that three persons could normally be expected to be working from a 10.7-m (35-ft) fire service ground extension ladder. According to ANSI A14 criteria, this would be a "special purpose ladder" and not within the scope of the present ANSI A14.2 document. It is possible to take the performance criteria of the ANSI A14.2-1972 publication and upgrade the load requirements to provide equivalent performance for a three-person product.

The authors noted that, in the ANSI standard, ladder jacks and stages or planks can be used on medium and heavy duty ladders. A decorator plank is rated for 113.4-kg (250-lb) working loads. A scaffold plank is rated for a 226.8-kg (500-lb) working load. In order to use one of these products, a typical installation requires a minimum of two extension ladders from which the ladder jacks are installed to support either the decorator or scaffold plank. The load is divided between the two ladders, and consequently it is difficult to understand how the authors concluded that an extension ladder could easily have the equivalent of a three-person load.

The ladders and planks generally have instruction labels and specific information identifying the rated load capacities. A user exceeding these load ratings could not be considered to be performing a sensible act or one demonstrating sound judgment. Consequently, it cannot be termed "reasonable."

The horizontal bending test is not always the critical performance requirement that defines the design of an extension ladder. Certain requirements control in the case of one length of ladder, while others become critical for a different length. The committee recognizes that interplay between various requirements may result in horizontal bending being the key performance specification for one product, while deflection might be the controlling specification for another.

The paper strongly emphasizes the "column effect" in producing increased bending due to extension ladder deflection. ANSI A14.2-1972 recognizes this effect by means of the deflection test. Thus, the increased bending moment due to eccentric column loading is limited.

In an actual situation in the more sensitive longer ladders, the potential added moment is offset by a reduced dynamic effect that is due to the greater absorption of energy.

The Ladder Failure

NFPA is specific in requiring that materials used in a metal fire ladder meet, or exceed, certain minimum yield strength and ultimate tensile strength levels. This ladder did not comply with these requirements.

The lower than minimum property val-

ues did render the product defective. The horizontal bending test as now stipulated does not incorporate sufficient load to imply or infer a safety factor of 4. The authors' assumption is *not* valid, and, in fact, the 23% lower yield strength of the base section did significantly erode the ladder's capability to meet the performance expected during the passing exercise.

The Horizontal Bending Test

The horizontal bending test, as described in the ANSI A14 standard, represents a compromise between different interests. The resolution of forces that the authors reviewed in their appendix is, in fact, partially simplified in that friction at the top and bottom of the ladder, impact of overlap and guide iron design, and similar factors have not been considered. The literature is replete with this information. The ANSI A14 Testing Task Force has very seriously studied this test versus what we in the testing task force term the "simulated in-use inclined load test." A number of manufacturers have been using the inclined use test for many years in their internal design process.

The inclined use test would answer the complaints or objections proposed concerning the horizontal bending test. The test is much more difficult to perform and is inherently less reproducible. Its use has been challenged because a relatively high vertical support is necessary against which to place the ladder. The availability problem is not difficult to overcome for short ladders, but with product 8.5 m (28 ft) and up, the degree of difficulty increases. There is a safety hazard that must be recognized, and resolved, when one applies the test load to the ladder. This would be particularly important were there to be a test failure. The ease of performing the test is consequently restricted; hence, there is concern among various interests about the procedure being adopted.

A14.2-1972 states, in a footnote to Table 3, "The test load incorporates the required safety factor of 4 on horizontal bending." This safety factor of 4, as such, was not intending to measure the actual safety factor of 4—in use. The ANSI A14 Testing Task Force further recognizes that the test span is 0.3 m (1 ft) less than the length of the ladder in an in-use situation, which will affect the maximum bending moment. Further, the horizontal bending test did not incorporate any consideration for the actual load. Other factors, including dynamics, have been considered.

TABLE 1—*Strain measurements for static horizontal bending and dynamic use tests (Type I aluminum ladder).*[1]

Test Condition	Test Load, lb	Strain (10^4 In./in.) 28-ft Ladder Fully Extended (25 ft) Average	Highest Value	28-ft Ladder Cut Back to 20 ft—Fully Extended (17 ft) Average	Highest Value
Horizontal bending	200 Static	19.3	20.1	12.5	13.0
75.5° inclination	205 Dynamic	12.0	12.8	11.3	12.4
70-deg inclination	205 Dynamic	15.8	17.0	11.1	12.2
65-deg inclination	205 Dynamic	16.4	17.6	13.3	14.4
60-deg inclination	205 Dynamic	18.0	19.6	13.6	15.6

[1]The source for this table is ANSI A14 Testing Task Force Document 166, Tables 20–21, "Report on Dynamic Tests of Ladders," Case Western Reserve University. The data represent the average of all gage readings reported.

TABLE 2—*Ultimate failure loads in horizontal bending and inclined use tests (Type III—20-ft aluminum extension ladder).*[1]

Test Condition	Horizontal Bending	75.5-deg Inclination	60-deg Inclination
Ultimate Test Load at Center Overlap Rung Location, lb	250	1100	500
Ratio of Ultimate Inclined Load to Ultimate Horizontal Bending Load	—	4.40	2.00
Ratio of Ultimate Inclined Load to Rated Load Capacity of 200 lb for Ladder	—	5.50	2.50

[1]The source for this table is ANSI A14 Testing Task Force Document 187. It should be noted that a 20-ft extension ladder has a 17-ft working length and a 16-ft horizontal bending test span. The load was applied on a rung via $3\frac{1}{2}$-in.-wide straps adjacent to both side rails for horizontal bending and equally to both rails via a bar through a rung for inclined load tests.

TABLE 3—*Ultimate inclined use test loads for 75.5 and 70.5-deg angles (Type I—heavy duty, 250-lb duty rating, aluminum extension ladders).*[1]

Ladder Size, ft	Working Length, ft	75.5-deg Minimum Test Load Capacity, lb	Actual Load Causing Failure During Inclined Use Test, lb: 75.5-deg Inclination	70.5-deg Inclination
16	13	1000	1350	1050
28	25	1000	1475	1000

[1]The source for this table is ANSI A14 Testing Task Force Document 70. Failures at reported loads were rung failures. At 70.5 deg the 28-ft unit had rail failure at 1300 lb. The load was applied at the centermost rung over a central $3\frac{1}{2}$-in. strap.

A14 Testing Task Force files provide some actual test data to compare horizontal bending and inclined use tests. Table 1 summarizes strain gage measurements for both static horizontal bending and dynamic inclined use tests. After the horizontal bending tests, the ladder was erected at the various angles of inclination, and a 93.0-kg (205-lb) climber both ascended and descended. Average and highest strain gage readings are reported for both the 8.5-m (28-ft) ladder fully extended to its 7.6-m (25-ft) working length, and the unit when cut back to a 6.1-m (20-ft) size with an extended length of 5.2 m (17 ft). Strain increased 1.5 times as the 8.5-m (28-ft) ladder angle moved from 75.5 to 60 deg. The same ladder cut back to 6.1 m (20 ft) resulted in a lower strain level.

Table 2 reviews the load required to achieve failure in horizontal bending, and at various "use" inclinations. The data indicate the reserve capacity inherent in

the metal extension ladder prior to failure. At 60 deg the actual load capability declined, although less than theoretical calculations would have forecast. Actual loads, which caused failures during inclined use tests for 70.5 and 75.5-deg inclinations on 4.9 and 8.5-m (16 and 28-ft) extension ladders, are reported in Table 3. Even at 70.5-deg inclination, the products had a load capacity of 4 times their duty rating.

The defects in the fire ladder could have been identified by using a portable hardness tester, or an in-service horizontal bending test. Such a test method would require individual manufacturers to establish loads and resulting deflections that would not induce excessive strain.

Foreseeable Conditions of Ladder Use

Portable ladders must combine strength with lightness to minimize the effort required in handling and transporting the product. Excessive weight will increase the possibility of safety hazards during handling and manipulation of the ladder.

The authors appear quite concerned over the anticipated angle of inclination at which the ladder will be used, and also the loading of the ladder. Fire ladder standards must anticipate ladder usage from the preferred angle of 75.5 deg through 70.5 deg, and down to 60 deg as normal usage. From this point to 45 deg or less, they conceivably can expect limited use in emergency situations. NFPA 1931-1975 established a maximum ladder loading (working load) of 272.2 kg (600 lb) on extension ladders of 8.2 to 13.7-m (27 to 45-ft) lengths. They proposed that the ladder be used applying the quarter-length rule. If the angles were reduced to 45 to 60 deg, they then suggested that the load be reduced by 68.0 to 204.1 kg (150 to 450 lb) maximum. For ladders employed at less than 45 deg, they suggest that no more than one person be on the ladder at any one time. NFPA 1931-1975 has addressed itself to the problem of reduced loading with decreases in angle of inclination.

Fire departments are relatively explicit in the number of fire fighters and weight of hose and other gear that they would anticipate employing on a ladder. These fire fighters are very carefully trained and periodically retrained. The ladders are designed specifically with butt spurs or equivalent devices to develop the maximum possible slip resistance at the bottom of the ladder. Fire fighters are trained to work with—and from—ladders, so that they have a substantially higher level of skills and knowledge than does the lay ladder user. The heavier weight of their ladders, coupled with the number of persons on the ladder, and the ability to provide a "footing" function if necessary, reduce some of the hazards when these ladders are employed at the more dangerous angles of inclination.

The fire services' methods of climbing tend to reduce hazards at the less steep angles. In contrast, the portable ladder user has less training, employs a lighter ladder, is working alone or with an unskilled helper, and is less aware of the dangers of ladder foot slip.

Early publications recommended: "Portable ladders should be used at a pitch such that the horizontal distance from the top support to the foot of the ladder is one-quarter of the length of the ladder" [8]. Hepburn [9] explored the problems of foot slippage in great detail. The required coefficients of friction at the foot of the ladder to resist the foot slipping depend only on the angle of the ladder and the climber's position on this product. The weight of the climber has no influence. Hepburn's theoretical analysis indicated that sliding may occur when the climber is halfway up the ladder at an inclination of 62 deg, three-quarters of the way up the ladder at an angle of 71 deg, and 90% of the way up the ladder at an angle of 74 deg.

Slow climbing speed and a heavier ladder both improve the stability situation. Consequently, A14 in its portable ladder standards must continue to use 75.5 deg as the preferred ladder angle for extension ladders. Designing ladders so that they can have an increased safety factor for structural loading at 60 or 55 deg will not prevent ladder accidents.

A study of 248 accident cases [*10*] indicated that 56% were the result of ladders slipping. CIS Information Sheet I2 [*11*] in its introduction stated: "Numerous investigations have shown that less than 20% of all ladder accidents are attributable to defective equipment; the other 80% are due to the thoughtlessness and foolishness of ladder users." The U.S. Consumer Product Safety Commission's studies [*12*] indicate that perhaps 85 to 90% of all ladder accidents are the result of misuse or abuse on the part of the ladder user.

The question of load rating must be addressed. Portable ladders covered in the A14 scope are specifically intended for one-person operation. In contrast, ground ladders employed by the fire service range from one to several persons in their intended loading, depending upon the design of the product and its length. The use of ladder jacks, combined with decorator planks or scaffold planks, would not increase the loads above the 113.4-kg (250-lb) duty rating of the Type 1 product. There are applicable standards for planks, ladder jacks, and ladders that give guidance in this area. It is unreasonable to anticipate three-person loadings in this particular application.

CIS-I2 [*11*] justifies the A14 Portable Ladder Standards Appendices' providing so many prohibitions as to what some people might conceive to be reasonably foreseeable use patterns.

Standards for Performance

The authors' assumption that portable metal ladders should have capability of 3 times the current level of loadings results in their conclusion. We believe that this is invalid for ladders built to comply with the ANSI A14 standards. In the case of the accident described in this paper, we believe that the cause was side-rail material that did not meet the specified minimum level of mechanical properties.

The horizontal bending test uses "permanent set" as its acceptance criterion. It is conceivable, if the ANSI horizontal bending test were employed, that it would not detect the reduced mechanical properties. However, if the test were used with an increased load to recognize design requirements of a three-person ladder versus the one-person criterion of ANSI, we would expect this product to develop permanent set and be rejected.

Although we can agree with the authors of the paper that the current ANSI horizontal bending test is a "simplified" procedure, it is illogical to propose 3 times the current load requirements based upon the arguments presented in the paper of "foreseeable usages."

The ANSI standards require more than just the horizontal bending test to be met in order for a manufacturer to comply with the performance requirements.

Currently, proposals are being studied that would establish both design verification test and in-service test procedures for a number of requirements. The new standards will incorporate an inclined use test requirement. This test method has been used for years by manufacturers.

When numerous studies indicate the major cause of accidents to be misuse or abuse, then user education [*13*] might sig-

(*continued on page 46*)

ANSI Discussion of the Ladder Standard
(continued from page 18)

nificantly improve the situation. The ladder industry, in its many facets, has been—and is today—strenuously pursuing various educational activities in an effort to make users more aware of the inherent hazards that one must appreciate when employing ladders. Toward this end, the ladder industry in April 1976 initiated a new type of labeling program that separately identifies primary and secondary hazards in an effort to reduce the propensity for accidents. Included in this program are labels designed to assist the user to set the ladder easily at the 75.5-deg preferred angle. Other labels cover such considerations as the "highest standing level" of the particular product, setup and use instructions, and similar information.

Conclusions

We have responded to the authors as we deemed it necessary to state our differences with the opinions outlined in their paper. The fact that they have developed such a thoughtful work is very much appreciated by the members of ANSI Committee A14, and particularly by the testing task force. Other reviewers' comments are also available.[2]

REFERENCES

[1] "Safety Requirements for Portable Metal Ladders," ANSI 14.2-1972, American National Standards Institute, New York, 1972.

[2] "Fire Department Ground Ladders," NFPA 1931-1975, National Fire Protection Association, Boston, Mass., 1975.

[3] *Fire Service Ground Ladder Practices*, 7th ed., International Fire Service Training Association, Oklahoma State University, Stillwater, Okla., 1973, p. 39, #19.

[4] "Mechanical Tests and Analysis of Fire Department Ground Ladders," NBS Report 10 474, National Bureau of Standards, Washington, D.C., Aug. 1971.

[2]Reviewers' comments can be obtained by writing the ANSI A14 Ladder Standards Committee, in care of Thomas F. Bresnahan, secretary, Alliance of American Insurers, 20 N. Wecker Dr., Room 2140, Chicego, Ill. 60606. They include: letter from Gordon L. Lemke to Professor Alvin S. Weinstein, 1 April 1977; letter from Gordon L. Lemke to Professor Alvin S. Weinstein, 19 April 1977; letter from Samuel C. Cremer to T. F. Bresnehan, 22 April 1977; end letter from Claude R. Wallick to T. F. Bresnahan, 8 April 1977.

[5] "Fire Department Ground Ladders—Results of a Preliminary Study," NBS TN 833, National Bureau of Standards, Washington, D.C., July 1974.

[6] *The Fire Chief's Handbook*, Case-Sheppard-Mann Publishing Co., New York, 1958, p. 145.

[7] "Tentative Standard for Aluminum Ground Ladders for Fire Department Use," Underwriters' Laboratories of Canada, Scarborough, 1961.

[8] "Model Code of Safety Regulations for Industrial Establishments for the Guidance of Governments and Industry," International Labor Office, Geneva, 1949, Regulation 211—"Equipment and Tools," p. 403, para. 22.

[9] Hepburn, H., "Portable Ladders—Part I, The Quarter Length Rule," *British Journal of Industrial Safety*, Vol. 4, No. 46, 1958, pp. 155–158.

[10] "Survey of Accidents Caused by Slips and Falls from Poles and Ladders," TD-8 Branch Investigation Report 206, Engineering Safety Office, British Post Office Telecommunications Headquarters, London, 1971.

[11] "Ladders," CIS Information Sheet 12, International Occupational Safety and Health Information Centre (CIS), International Labor Office, Geneva, Dec. 1966.

[12] Fandey, J.E., "Briefing Paper on a Petition from Frederick Saphra, P.E.," CP-75-9, U.S. Consumer Product Safety Commission, Washington, D.C., and "Request Standard Development for Aluminum and Magnesium Ladders," Office of Standards Coordination and Appraisal, 24 Aug. 1976.

[13] "Ladders," Fact Sheet 56, U.S. Consumer Product Safety Commission, Washington, D.C., Feb. 1976.

Article from ASTM Standardization News, September 1978

Discussion of "The Ladder Standard: How Successful the Climb?"

By Samuel C. Cramer

The following discussion of the paper by Alvin S. Weinstein and John C. Frank, "The Ladder Standard: How Successful the Climb?," was written by Samuel C. Cramer on behalf of the Ground Ladder Subcommittee of the National Fire Protection Association's Fire Department Equipment Committee. Cramer is chairman of the NFPA subcommittee.

The Ground Ladder Subcommittee of the NFPA Fire Department Equipment Committee wishes to take exception to the paper entitled "The Ladder Standard: How Successful the Climb?," which was written by Alvin S. Weinstein and John C. Frank and presented at the ASTM symposium, "Technical Standards in Products Liability Litigation," 5 May 1977 in Toronto.

Principle among our exceptions is the reference to NFPA 193, "Fire Department Ladders, Ground and Aerial," as the current standard outlining performance requirements for fire department ground ladders. NFPA 193 was completely revised in 1975 and renumbered as NFPA 1931, "Fire Department Ground Ladders." In fact, this NFPA standard has been revised twice since the ladder mentioned was manufactured.

The following remarks reference sections of NFPA 1931-1975, "Fire Department Ground Ladders" [*1*], the most current NFPA standard for ground ladders. The statements follow the same order as the captioned paper and reference appropriate sections within NFPA 1931.

Introduction

The Ground Ladder Subcommittee has presented "reasonable foreseeable" performance requirements for ground ladders. Section 8-1.3 provides a guide for recommended maximum ladder loading.

The Incident

The passing exercise stated is *not* a typical fire service operation. The International Fire Service Training Association (IFSTA) in the seventh edition of *Fire Service Ground Ladder Practices* [2], no longer recommends passing on ground ladders. They state:

> When it is necessary to perform a rescue down a ladder, all of the loads and activity should be removed and the ladder should be securely anchored at both the top and heel, when possible.

Therefore, the third man on the ladder should not have been permitted on the ladder during the passing operation, which duplicates an emergency load of two people in one position. Also, as this passing operation was undertaken numerous times during the two-hour training period, why should the ladder be expected to be overloaded more than once?

Regarding the ladder condition, one questions the history of ladder usage prior to the incident. Had the ladder been weakened due to previous exposure to heat or flame? How was it used?

The ladder angle as utilized was less than the optimum as indicated in Section 10-4. The load-carrying capacity would be reduced reflective of this reduced angle.

Standards of Performance

Extension ladders are not tested by "treating each individual section as a single ladder" as indicated in the Weinstein and Frank paper. Section 8-3, Horizontal Bending Test, provides:

> Extension ladders shall be extended to the maximum extended position. The test load shall be applied across the center of the ladder.

The scope of ANSI 14.2-1972, "Safety Requirements for Portable Metal Ladders" [3], states:

> This standard is intended to prescribe rules and minimum requirements for the construction, care, and use of the common types of portable metal ladders in order to ensure safety under normal conditions of usage. It does not cover special-purpose ladders which do not meet the general requirements of this standard.

ANSI does not consider fire service application as a "normal condition of usage." Rather, ANSI has adopted NFPA 1931-1975 (ANSI Standard A14.7-1976) as their fire department ground ladder standard. To compare ANSI A14.2 and ANSI 14.7 confuses the major environmental differences to which these respective ladders are exposed.

Referring to the paragraph, "Performance Implications," NFPA 1931 does not indicate personnel-carrying capacity for ground ladders. To indicate carrying capacity by personnel complement is unresponsive to the wide range of personnel and equipment weights within the fire service.

Section 8-3(d) requires a horizontal test loading of 113.4 kg (250 lb), contrary to the 90.7-kg (200-lb) loading indicated in the paper.

The authors' assumption of providing a critical performance requirement utilizing an equivalent three-person center loading would produce a product that fire fighters

(continued on page 48)

NFPA Discussion of the Ladder Standard
(continued from page 19)

would be physically incapable of utilizing in the performance of their rescue mission.

The Ladder Failure

Reiterating the opinion of IFSTA, the passing procedure is *not* a "typical" performance requirement of a fire service ground ladder. The concentration of personnel, as in a passing procedure, is similar to an emergency rescue operation where all other loads are removed from the ladder with ladder tip and heel anchored, when possible.

Weinstein and Frank indicate significantly reduced product performance because of poor quality control in the ladder manufacture; therefore, their conclusion should indicate the need for greater quality control on the part of the aluminum producer and/or ladder manufacturer. To assume a 23% lower yield strength in base section side rail material as not significant completely overlooks the minimum performance requirements required of the final product.

Standards for Performance

We agree that a performance requirement based solely on one test, horizontal bending, is totally inaccurate. Present fire service ladders, manufactured to meet NFPA performance requirements, are tested for horizontal bending, hardware performance, rung bending strength, rung-to-side rail shear strength, rung torque strength, and unit deflection.

We take exception to the statement ". . . NFPA ladder standards serious underestimate reasonably foreseeable use patterns . . . ." Section 8-1.3 addresses maximum ladder loading by providing guidelines for the fire service considering anticipated ladder usage.

Conclusion

In conclusion, the subcommittee agrees that the user wants a ladder that retains an adequate margin of safety based upon a foreseeable-use environment. The ladder must, however, be used in accordance with the regulations that provide such an environment. For these reasons, there are ongoing programs within NFPA and ANSI that will result in improvements in ladder standards. Agencies assisting in these programs include the National Bureau of Standards, Underwriters' Laboratories, the Aluminum Association, and the National Forest Products Laboratory, as well as many other concerned groups. We hope that the interest expressed by the authors in improving the safety of ladders can be utilized by the NFPA subcommittee.

REFERENCES

[1] "Fire Department Ground Ladders," NFPA 1931-1975, National Fire Protection Association, Boston, Mass., 1975.

[2] *Fire Service Ground Ladder Practices,* 7th ed., International Fire Service Training Association, Oklahoma State University, Stillwater, Okla., 1973.

[3] "Safety Requirements for Portable Metal Ladders," ANSI 14.2-1972, American National Standards Institute, New York, 1972.

Now that you have had the opportunity to review the comments which Werner and Cramer made on behalf of the respective committees which they chaired, what is your reaction? What suggestions can you make for improvement in either standard, or in related standards?

Standard Ladder Standard

Part C

THE ANATOMY OF A LADDER STANDARD

Robert I. Werner
R. D. Werner Company, Inc.
Franklin Park, Illinois

Paper from the Products Liability Prevention Conference Proceedings, ASQC, 1977

INTRODUCTION

The American National Standards Institute (ANSI) Standards Committee A14 has responsibility for development of Standards covering Safety Requirements for Portable Ladders. The Committee organized in 1922, and issued the initial Standard for wood products in 1923. The first Metal Portable Ladder Standard was issued in 1956, and for Reinforced Plastic Ladders in 1974. Subsequent revisions to the wood requirements total 7, and for metal 2. The latest issues of these documents are, respectively:

A14.1-1975 - Wood[1],
A14.2-1972 - Metal[2], and
A14.5-1974 - Reinforced Plastic[3].

The Wood Standard is considered a specification orientated document, while the Metal and Reinforced Plastic Standards are termed 'performance standards'. One finds a great deal of detail covering types of wood, dimensional requirements and similar specific statements in the A14.1 document, while the other two Standards rely upon statements concerning the tests the product must meet without necessarily describing the specific dimensions of the ladder rail which might comply with the requirement. In practice, in all of the Standards, the reader will also encounter a combination of both specifications and performance requirements because there are certain situations that can best be handled by specification while others can be properly described by a performance requirement.

In addition to the specifications or performance requirements, the Standards contain Care and Use data which is highly significant from an educational viewpoint. Studies of ladder accidents by different groups have indicated that misuse and improper use are involved in 80 - 90% of ladder accidents. Education and improvements in the training of ladder users therefore represents one of the most effective means of reducing ladder accidents.

ANSI procedures require that the Standards be reviewed every 5 years. The Portable Metal Ladder Standard was being reviewed as of June 25, 1975 for a 1977 revision. The ANSI A14 Testing Task Force commenced work on October 3, 1975 to review all existing and potential test methods and procedures that would apply, not only to metal portable ladders, but also to wood and reinforced plastic products, as well. This group had 22 meetings through June, 1977. In addition, there were meetings involving the U. L. Industrial Advisory Council, the U. S. Consumer Product Safety Commission, and the A14 Advisory Committee. There were also additional meetings involving the A14 Labeling Task Force, the A14 Anthropometric Task Force and the A14 Testing Task Force Human Falls Experiment Group.

Wood Ladder Standard-writers enjoyed major technical support and substantial wood technology research contributions from the USDA - Forest Products Laboratory whose personnel served in the capacity of Chairman of ANSI A14.1 for many years. Technical support of the underlying materials used in metal and reinforced plastic ladders has been provided by the collective activities of both the material suppliers and the ladder manufacturers, coupled with joint efforts within the respective Portable Ladder Subcommittees.

Each of the Subcommittees have been carefully balanced by the Secretariat to ensure that the consensus does, in fact, represent an equitable balance of the viewpoints of the parties involved. The ANSI review and approval process ensures the development of a legitimate consensus.

The Federal Interagency Task Force on Product Liability "Briefing Report"[4] and their reference - "The California Citizens' Commission on Tort Reform"[5] - identified ladders as a "high hazard product". The U. S. Consumer Product Safety Commission considered a petition for a mandatory standard for these products, which was denied[6]. Results of CPSC efforts to quantify and identify hazards have been meaningful. CPSC representatives formally participate as observers in the monthly ANSI A14 Testing Task Force Meetings, and, generally, all of the other meetings relating to the Standards Review project.

Building upon work initiated within individual companies, the A14 Testing Task Force developed several different types of survey forms which were implemented to acquire significant knowledge concerning ladder usage patterns, age and accident information. The development of a safety standard involving ladders or similar products, represents, in part, an evolutionary process. The working group consists of a number of qualified people each having perhaps different biases and interests. Trade-offs are made which represent informed judgments, or balancings of risks versus benefits and advantages.

The technical paper "The Ladder Standard: How Successful the Climb?"[7] initiated a dialogue and a formalized response from the ANSI A14 Testing Task Force[8]. It became apparent that the process of standards-making and standards development might well be explored utilizing a "real life" example.

Certainly the projections in the California Citizens' Commission on Tort Reform[5] (Exhibit 25) of 73,000 injuries requiring emergency room care for ladder associated accidents, with the resulting 400 - 500 product liability lawsuits, would further justify some additional review.

In discussing ladder accident theories, the results of a wide range of accident investigations are considered. It became rather apparent that the same "raw data" would be interpreted differently depending upon the skills and training of the persons performing the analysis. It is somewhat difficult for the newly designated ladder accident reviewer to accept the repeated assertions of industry engineers concerning the cause of an accident until they have been a witness to sufficient ladder tests so that their independent knowledge permits a properly qualified assessment.

The questions of "useful life" as well as "intended use" versus "actual or reasonable foreseeable use or misuse" are considered.

Many active experts in various phases of the ladder industry opened their files to the A14 Testing Task Force. The data bank provided to this body is replete with examples of ladders tested to ultimate

failure, tested utilizing predamaged components, or components which had induced failures in them. They all met fairly rigorous performance tests. The research activities highlighted the principal causes of ladder accidents drawing from several different sources of data. Efforts were made to develop meaningful criteria to evaluate product performance. The limits established by basic scientific principles, available material, and like considerations, resulted in the Testing Task Force defining, in essence, the current "state-of-the-art". A prime example would be the means available to generate higher co-efficients of friction of ladder feet when extension ladders are inclined at certain angles.

Comments, be they positive or negative, were solicited from the public as well as the group of approximately 200 independent engineers and scientists which we termed "Outside Experts". Some 61 experts were involved in in-depth solicitation, following which 20 joined specific Task Groups. Their input was carefully evaluated. Where the responder provided sufficient information for a test to be performed, it was performed in an effort to provide meaningful data to the Task Force. Witnessing such tests enabled us to have a better understanding of just what was occurring. Several tests which were considered for either stepladders or extension ladders have been highlighted.

Data reduction techniques were introduced. The use of linear correlations and statistics aided in developing a more consistent approach to ladder performance. Frequently we have found that the size of ladder was more significant for certain types of performance criteria than the "Type" ladder.

The collective efforts of the Task Force are embodied in three volumes of documents through June, 1977, totaling 275, plus a very thick volume of meeting Minutes and a separate book of test methods and procedures. The final product will embody a rationale. Every effort is being made to ensure that the "Standard" can stand on its own feet.

Education is perhaps the most important means to reduce ladder accidents. Efforts have been initiated to both improve the quality of the education as well as the consumer exposure.

BACKGROUND STATISTICS AND INFORMATION

Portable ladders are tools used by both consumers and tradespeople. The opportunity to have accidents, or the high hazard potential of the product is well known. The need for periodic training of users is often not well recognized. The necessity for inspection prior to use has been well publicized, but is, in fact, frequently overlooked.

One of the most worthwhile publications our literature searches have uncovered is available through the International Occupational Safety and Health Information Centre (CIS) and is entitled CIS-12 - "Ladders"[9]. It reports: "Numerous investigations have shown that less than 20% of all ladder accidents are attributable to defective equipment; the other 80% are due to the thoughtlessness and foolishness of the ladder users."

CPSC, principally concerned with consumer ladders in the "Briefing Paper"[10], stated: "A review of injury data ..... indicates that injury patterns are the same for wood as for metal ladders."

It was further stated that "Approximately 80% of all injuries involving ladders involve some degree of misuse. Misuse includes such actions as:

A. Improper positioning of a ladder at unsafe angles or on unsafe ground (unlevel or soft ground, or wet leaves or grass) without securing the ladder by tying it down;

B. Climbing to the top two rungs;

C. Shifting body's center of gravity to a point outside either siderail;

D. Improper maintenance;

E. Entering or exiting ladder at roof levels on improper size ladder or with improper positioning or securing;

F. Attempting to manipulate a ladder which is beyond the user's capability to accomplish by himself;

G. Failing to engage locks or spreaders;

H. Using while under the influence of drugs or alcohol;

I. Wearing wet or other slippery shoes."

These statements are supported by the CIS-12 data for both consumer and industrial applications.

In October, 1976, CPSC issued "Product Profile - Ladders"[11]. This reported for calendar year 1975 an estimated total injuries of 211,411, of which 80,336 were treated in emergency rooms. The mean severity was 37. The number of emergency room visits requiring hospitalization totaled 9,095, for a frequency of hospitalization per 100 injuries of 11.3. There were 174 deaths. The profile further indicated that in the age groups of 15 - 64 years, as well as 65 years and over, the statistics for emergency room treatments and hospitalization required exceeded the population proportions.

Periodically CPSC issues summaries on the NEISS (National Electronic Injury Surveillance System) activity[12]. These publications, plus other reports[5,10,13,14], contain statistics which vary somewhat period to period.

The <u>Product Profile - Ladders</u>[11] indicated an "estimated useful life of 20 - 30 years". It claimed "a usage frequency of one time per month for ladders", and further stated:

"The use of a ladder assumes a high degree of voluntary risk on the part of the user."

CPSC and National Bureau of Standards staff analyzed a series of 225 in-depth investigative reports (IDIR)[15] covering accidents. Following their evaluation, a team of experts skilled in accident reconstruction reviewed all of the cases with representatives of CPSC and NBS. These A14 Testing Task Force members determined, in the case of these 225 reports[16], that:

For <u>stepladders</u>,

43% of the accidents were due to attested misuse;

53% of the accidents were due to stability; and only
0.6% of the accidents were due to structural causes.

In the case of extension ladders, they found
35% of the accidents were due to attested misuse;
62% were due to ladder slip (in Europe it runs 56%[17]); and
2.4% were due to structural failures.

The studies further showed that 20% of the accidents represented overreach in the case of stepladders, while 45% of the stepladder accidents occurred when the user was at, or near, the top of the product. For extension ladders, the ladder slip category was further subdivided so that:

62% of the accidents occurred with foot slip, while
38% occurred with the ladder top end slipping.

A Ladder Use Survey was answered by a total of 2,372 respondents. Included were employees of ladder manufacturers, utilities, members of ANSI/ASTM Consumer Sounding Boards across the United States, personnel responding through the National Safety Council request for participation, and finally, 1,793 Sears, Roebuck consumer panelists. This latter group was individually identified so that further information could be solicited.

Ladder Use Survey

General comments from the total questionnaires returned revealed the following statistics:

A. 23.1% of the ladders were reported damaged.
B. 10.5% of users employed damaged ladders usually, while 16.5% did so occasionally.
C. 2.7% usually employed metal ladders when working on live electrical wires or near exposed wiring, while 14.0% did so occasionally.
D. 9.8% of the answers revealed people using ladders horizontally or in another position other than for climbing.
E. 20.4% had not read the labels.
F. 678 people reported they had fallen from ladders, which was 28.6% of the sample.
G. 82.3% were non-professional users.

In the Stepladder classification, the Ladder Use Survey showed:

A. 16.3% reported they climbed the back or rear of a stepladder.
B. 18.6% stood on a bucket holder or pail shelf.
C. 71.2% used a closed ladder which they leaned against a wall.
D. 59.7% stood on the top cap and from the sample, 36.8% stood on the top cap in order to climb higher.
E. 74.2% stood on the top step while 44.5% of the sample stood on the top step in order to climb higher.

The statistics for Extension Ladders revealed:

A. 13.8% didn't know proper extension ladder placement while only 25.3% located the ladder at the recommended angle.
B. 70.0% reportedly used the ladder in order to climb on a roof, while 44.2% did not provide enough extension of the ladder above the top support point.
C. 16.4% of the users reported difficulty in extending the ladder.
D. 17.5% reported some form of lock malfunction.
E. 25.3% of the extension ladder users tied off the top of the ladder to prevent movement either usually or occasionally.
F. 13.4% of users blocked or tied off the bottom of the extension ladder to prevent movement usually, and an additional 27.5% did so occasionally.
G. 0.46% of the people usually stood on the top rung of an extension ladder and an additional 9.7% did so occasionally.

The results from different groups within the sample were relatively consistent. Certain of the results have caused new tests to be developed to evaluate particular characteristics. Other aspects of the survey indicated lack of attention to care and use instructions even when the hazards were identified.

Prototype stepladders embodying certain potential design solutions were field tested and discussed with the Consumer Sounding Boards. The user was frequently prepared to assume additional risk in order to get the particular task accomplished, rather than getting a different ladder that would be more suitable for the job at hand.

Other surveys revealed that ladder users, when aware of the physical presence of observers, performed tasks utilizing proper care and use procedures. However, when unaware of being observed, they employed hazardous procedures.

Comments by participating Outside Experts generated an A14 report form entitled "Compilation of Portable Ladder Accidents Reported by Experts". This form has been employed in evaluating accidents reported from various sources. It is contemplated that a variation of this form will eventually be proposed as a recommended format through which to acquire post ladder accident data.

Continuing efforts generated a third form called a "Ladder Accident Questionnaire". The evolution has, in essence, resulted in a bi-level ladder use and accident questionnaire. The various forms are being considered for use by different groups. The resulting data, with greater experience, should be of substantially increased value.

Ladder Accident Questionnaire

From the Sears Consumer Panel respondents, the 400 panelists who indicated that they had had an accident on a previous ladder use questionnaire, were sent the Ladder Accident Questionnaire form. In this sample, 36% reported 'no injury'; minor injuries were reported by 45% (bruises and cuts); and 19% had serious injuries (fractures and sprains).

The returned sample indicated that:

A. 19% were not utilizing the proper ladder for the job.

B. 27% acknowledged placing the ladder incorrectly at the work site.

C. 40% of the people involved in falls had not read the labels or any of the literature associated with the ladder prior to using the product.

Although 3/4 of the accidents occurred outside, a larger proportion of the accidents generating serious injury occurred indoors. In serious accidents, a greater proportion than average occurred while working on a roof or on gutters.

Almost 1/2 of the serious stepladder injury accidents occurred when a person was standing on the top step. Half of the total stepladder accidents occurred when the person was standing on one of the top two steps.

Users reported 1/2 of the accidents occurred when they were reaching up or to the side, and when they caused the ladder to tip or lost their balance.

CPSC Analysis

The Bureau of Engineering Sciences[10] had established, for their purposes, different categories of causations. Structural failures were reported in 4 - 5% of the cases. Reasonable foreseeable misuse was attributed to 23% (stepladders) to 33% (extension ladders) of the accidents. Misuse was 57 - 58% of the accidents. They claim no apparent ladder factor in 6 - 8% of reports. In the case of extension and straight ladders, 6% of the accidents represented electrocutions.

We thus have a wide range of statistics which, in general, indicate that misuse is a major causation. Further, that structural failures are a minor factor, particularly when the gross analyses are dissected. Often, what is initially termed "structural failure" has been shown later not to be the cause, but rather one of the results of the accident incident. The Sears panelists' report revealed 22.3% having had accidents. The 53% of this group which responded to the 2nd level questionnaire assisted greatly in identifying more of the causes. All of the data gathered from the various sources is being employed by the ANSI A14 Testing Task Force in their current Standards revision activities.

TRADE-OFFS

'Trade-off' has been defined[18] as "an exchange; especially a giving up of one benefit, advantage, etc. in order to gain another regarded as more desirable."

Lowrance, in "Of Acceptable Risk"[19], stated:

"A thing is safe if its attendant risks are judged to be acceptable.

"Distribution of risks, benefits and costs may be a political issue, but in many senses it is still an empirical matter.

"Safety is the degree to which risks are judged acceptable.

"Benefit is the degree to which efficacies are judged desirable.

"Equity of distribution of risks, benefits and costs is a judgment of fairness and social judgment."[20]

An array of considerations influencing safety judgments are presented in Table I[21].

*** ***

TABLE I
ARRAY OF CONSIDERATIONS

Risk assumed voluntarily	Risk borne involuntarily
Effect immediate	Effect delayed
No alternatives available	Many alternatives available
Risk known with certainty	Risk not known
Exposure is an essential	Exposure is a luxury
Encountered occupationally	Encountered non-occupationally
Common hazard	"Dread" hazard
Affects average people	Affects especially sensitive people
Will be used as intended	Likely to be misused
Consequences reversible	Consequences irreversible

***

These Standards are concerned with portable ladders. If the Standard establishes requirements that significantly increase the weight of the product, will the ladder still be employable as a portable ladder? Will an increase in weight generate, in itself, some hazards in use? Would the 87 year old Consumer Sounding Board panelist who requires a small, Type III platform ladder to gain access to her upper level cabinets, be "safer" standing on a chair because, in our wisdom, we insisted that the product meet requirements that drastically increased its weight and its overall size so that she could neither move the product or position it within her apartment?

There are a range of materials employed in constructing ladders. Certain of these materials, particularly wood, are only available generally in a limited range of dimensions. Should a Standard be "tightened" to allegedly improve the structural capacity of a product, when the hazard analysis does not indicate any such justification? What happens if in so doing we literally eliminate products that have been used for generations without being identified as a cause of accidents?

Certain sectors advocate significant increases in requirements for structural strength; yet repeated hazard analyses indicate that accidents will not be eliminated by even drastic increases in the structural capability of the ladder products. Should the Standard be altered to achieve this objective? What if, in so doing, a significant portion of the population are no longer able to afford ladders? Would it be safer if they stood on chairs or boxes, or worked off of shelving or tables?

Product age and useful life of products are recognized as factors influencing the safe use of ladders.

Should manufacturers be required to indicate estimates of the useful life of their products? Will this be used in time for advertising puffery, or will it be legitimately of value to the consumer? Does a user have a responsibility for the care, use and maintenance of a product he acquires? How can this be incorporated into a Standard? How does the user's age, health and dress influence safety?

The ladder Standards can take several different forms. They can address specifically manufacturers, and the requirements that their products must meet. They could be written to assist users, and user in-plant safety personnel in evaluating the products "in-service". Test requirements could be drafted to be easily comprehensible to a layperson. Experience has shown confusion, misinterpretation of procedures and intent to be widespread. They could be designed for use by regulatory agencies. In essence, each of the above groups have some unique needs.

Should these performance requirements be designed to have a high degree of reproducibility and statistical significance? Or should they represent simple tests that require virtually no fixtures, and little if any technical competence in order for them to be performed?

Are the needs of all parties better served with design verification tests, in-service tests, or both?

In the past, the published performance test requirements represented static test procedures. Various groups consider that the Standards must incorporate dynamic and even cyclic testing requirements. Should such requirements be part of a ladder standard, or should, following proper evaluation, equivalent static techniques be incorporated? Should performance tests take precedence over specification requirements? What about where it can be demonstrated that specifications will generate a more desirable product?

Are there hazards which cannot be eliminated or minimized by design solutions? Can these be effected by education and training?

Are intended uses obvious? Are foreseeable uses and misuses evaluated? Can the Standard address these areas adequately? Do user expectations exceed product capabilities?

There are hazards and risks when one tests a ladder. Will the tester recognize these?

Will the hazards of employing ladders that have been exposed to design verification tests be appreciated? Will the inherent hazards that may occur if in-service tests are not performed properly be recognized?

The characteristics of the surfaces on which ladders are placed or leaned against are very significant. The floor or ground is not always level and the ladder, within certain limits, must be expected to adjust to these conditions. If the design is too rigid, we have certain problems, - and if it is too flexible, we have others. How is this best measured? -- and what are the most appropriate limits? A similar problem occurs at the top support.

How stiff or limber should an extension ladder be? Will these characteristics be influenced by length? What effect will these various considerations have on the dynamic characteristics of an extension ladder?

How can the in-put from outside experts be honestly evaluated? How can comments of non-technical users or general interest groups be properly considered?

Has the Care and Use section of the Standards adequately addressed the needs of the user in this area? Have they complied with the various Courts' requirements with respect to the "duty to warn"?

What impact will the Genaust decision[22] have on 'duty to warn' and labels? Bell[23] stated: "The Genaust decision was based upon what the Court felt was common knowledge in the community. Namely, the danger of electricity and the fact that metal will conduct electricity."

How can the concerns of special interest groups, who have a vital interest in the Care and Use instructions of the Standard and proposed statements in labels, be addressed? How do statements recommended by the Standards Task Force for use in labels be resolved vs. objections of user groups who have work rules or potential labor relations implications as a consequence?

How do different people read and interpret statements required on labels or within the Standard itself, now, - and in subsequent years? Are these statements capable of being misinterpreted or misconstrued?

To what extent must the labels cover the "duty to warn"? Are the current type statements sufficient or must they be expanded to introduce the consequences of the warning?

During the development of a revised Standard, these and many other considerations enter into the deliberations of the Standards-making body.

ACCIDENT THEORIES AND RESULTS OF INVESTIGATIONS

Hagglund[24] discussed causes of injury in industry and reported - based on a 1973 study in Wisconsin - that "unsafe conditions were found to comprise somewhere around 54% to 58% of causes uncovered, and unsafe acts were reported in only 26% to 35% of those cases which were investigated". This is in contrast to an earlier study by Heinrich[25], a strong proponent of the "unsafe act" theory of accident causation. Proponents of this theory contend that "approximately 85 - 90% of all injuries result from some unsafe act, and only 5 - 15% of injuries result from unsafe working conditions or undetermined causes". Neither of these theories address ladders specifically, however, Employers Insurance of Wausau[26] reported that portable ladders were in the 8th place out of 1,000 elements or objects involved with on-the-job injuries. They reported that falls represented 82% of the injuries, near falls were 11%, handling an additional 4%, and miscellaneous causes were 3%. They further stated:

"Cases where a ladder proved defective - where it failed during use - were so infrequent that we rated ladder failure as a negligible cause. .....faulty ladder use seems to be at the root of the majority of ladder accidents."

Supervisors need to explain to their subordinates the inherent hazards and the appropriate safety measures to take with ladders. Education should be employed in the vocational training schools toward this end. An excellent source of information is CIS-12 "Ladders"[9].

Considering the statistics, education is most important if accident reduction is to be accomplished.

Investigations following accidents can be most confusing. The injured party frequently may not recall all of the details involved in the incident. An attorney visited by an injured party accompanied by a broken ladder might conclude that there had to be a defect. A metallurgical analysis will strive diligently to determine the defect, even going to the extent of employing rather advanced techniques to prove the allegation. We frequently see what must be considered 'poor tests' in that they do not comply with recognized ASTM test methods for determining either mechanical strengths or chemical analysis of the materials. The use of non-standard methods may frequently result in an erroneous conclusion. Theories of failure causation and stress analyses are employed, often with certain fundamental assumptions. The results are not frequently verified by an experimental test to demonstrate the validity of the assumptions.

The experience with the Outside Experts Group within the ANSI A14 Testing Task Force is that response from outside experts is very limited. They tend to have some very strong opinions with respect to ladders but are quite guarded in providing guidance or comments in any form to the Standards-making community. If, in fact, there is an area that has not been properly addressed, then A14 openly and publicly welcomes constructive guidance.

Unfortunately, a broken ladder component, while a fact, does not imply that there was a structural failure in the ladder which was either a design defect or a manufacturing defect, or an inadequacy in the Standards requirements. A failure that occurs because a person lost his balance, fell off the ladder, and then fell on the ladder generating the fracture, is a situation where the failure is a result - rather than the cause - of the accident.

Battelle Columbus Laboratories[27] prepared an extensive report on the average life of ladders used by consumers, which showed that 95% of ladders produced were still in use up to 10 - 15 years thereafter. On a cumulative basis, 62.8% of the wood stepladders and 91.6% of the metal units range in age up to 15 years. In the case of extension ladders, the respective relations were 25.4% of the wood and 90.2% of the metal units. Additional data is found in Table II.

Products are not designed or manufactured for an infinite service life. A consumer expectation of a lifetime purchase when acquiring a ladder is unrealistic. The useful life is decidedly shorter than the 20 - 30 years reported in some surveys. It will vary with such factors as: frequency of use, degree of abuse in handling and storage, level of maintenance provided, and the initial design.

The condition of consumer ladders utilized by Battelle Columbus survey respondents is summarized in Table III. In stepladders, only 63.3% (wood) to 81.9% (metal) of the products were considered to be in excellent or good condition. For extension ladders the relations were 74.8% (wood) and 88.1% (metal).

Their studies indicated that on an average stepladders were utilized 30.2 times per year and extension ladders 18.0 times per year. In contrast, the A14 Testing Task Force[28] estimated that stepladders were used approximately 20 days per year and extension ladders 10 days per year for consumer applications.

Stepladder cyclic testing, using Battelle statistics, would mean that 10,000 load cycles would be the equivalent of 3.3 years and 50,000 load cycles 16.6 years.

Extension ladder cyclic testing - if adjusted - would mean that 50,000 load cycles is equivalent to 6.9 years and 100,000 load cycles to 13.9 years.

Cyclic tests to simulate service life situations have been performed within the Testing Task Force activity. Stepladder tests[29] showed almost 25,000 loading cycles in a step to siderail shear test with 900 pound loading. This is equivalent to 8 - 12 years of "use". At the working load level, various cyclic tests on stepladders indicated that well over 100,000 cycles generated no visible failure.

An extension ladder evaluation, utilizing an inclined use test[30], cyclic tested a Type III ladder at 200 lbs. (working load) for 150,000 cycles without any visual damage. This would be equivalent to 20 - 37 years of "use".

The working load is the combined weight of the user plus any tools or devices which are used on the particular Type ladder.

INTENDED USE VERSUS REASONABLE FORESEEABLE USE

Weinstein[7] claimed that the performance requirements in the Standards "appear to focus on the intended use of the product rather than the actual or reasonably foreseeable environment of product use". The response[8] answered the questions raised. It pointed out that portable ladders must combine the required strength and lightness in order to minimize the effort necessary in handling and transporting the product. Excessive weight of the ladder, itself, can represent a safety hazard during the handling and manipulation of the ladder.

The Portable Ladder Standards stipulate that "ladders are designed as one-man working ladders including any materials supported by the ladders". Performance tests and Werren's report[31] on Wood Stresses provides technical support for design calculations where necessary.

Definitions for 'reasonable foreseeable use' vary between those recognized in the Courts and normally understood by practitioners, such as engineers. In Illinois, the Court in Winnett v. Winnett[32] established a "foreseeability test" and stated "Foreseeability means that which is objectively reasonable to expect, not merely what might conceivably occur."

The literature is replete with discussions concerning care and use of ladders which are principally derivatives of the A14 Standards "Care and Use" sections. "Fact Sheet 56 - Ladders"[33] with its bibliography is an excellent example. CIS Information Sheet #12 - "Ladders"[9] reviews the consequences of misuse and improper use with extensive case histories.

An extensive patent search[34] of safety related products was carefully studied. Relating these devices to commercially available products, one finds the vast majority not to be readily acceptable to the user. Hepburn[35,36] describes several extension ladder accessories which would conceptually eliminate several of the improper use problems. They have not been accepted in use, although a version of the side-slipping device was marketed in the U.S. with limited success.

Dewar[37-40] explored the various factors contributing to extension ladder accidents. Best[41] and Binchal[42] evaluated various materials and foot designs. The A14 Testing Task Force[43] had extensive testing reports on this subject. It provides the most complete range of information covering the different combinations potentially available. The angle of inclination, the location of the user on the ladder, his weight, and the ladder's weight as well as the material on which the ladder is resting, all influence the results. Fox[44] reported co-efficients of friction for various ladder angles in terms of actual static measurements and dynamic measurements.

Dewar's work confirmed Hepburn's[45] earlier analyses. The concept of the "quarter length rule"[46] must be observed. It stated that "portable ladders should be used at a pitch such that the horizontal distance from the top support to the foot of the ladder is one-quarter of the length of the ladder."

As the various research indicated, the required co-efficient of friction at the foot of the ladder to resist the foot slipping depends only on the angle of the ladder and the man's position on the product. The man's weight has no influence. Theoretical analysis determined that slipping may occur when the man is 1/2 way up the ladder at an inclination of 62°; 3/4 of the way up the ladder at an angle of 71°; and 90% of the way up the ladder at an angle of 74°. Furthermore, slow climbing speed and the use of a heavier ladder would improve the stability situation somewhat.

This accumulative background has caused ANSI A14 to work toward the continued use of 75.5° as the preferred ladder angle for extension ladders. Designing ladders so that they can have an increased safety factor for structural loading at 60° or 55° will <u>not</u> prevent ladder accidents. In the IDIR analysis, there was no structuralladder failure occurring due to the use of too shallow a working angle of the extension ladder. This was true even with ladders erected at angles of 45° to 50°. In these situations the ladders slid away perpendicular from the wall (loss of base stability) or slipped parallel to the wall (loss of top stability).

Studies to evaluate means of reducing the extension ladder top slip problem were evaluated by the A14 Testing Task Force. The current materials or design variations afford virtually insignificant improvements. Dewar[38] concluded after extensive testing that with regards to the ladder slipping sideways, "it therefore seems safer to suggest that the man should keep his center of gravity between the stiles of the ladder." A heavier ladder, or a ladder used at a lower angle of inclination (below 75.5°) would be beneficial except that with lower angles the foot slip hazard increases.

The collective research indicates that the present level of technology does not offer a simple design solution to eliminate slipping problems that will be truly effective. Rather, education and improved instructions[47] appear to be today's answer. The most effective solution would be to secure the ladder before climbing or have a second person "foot" or hold the base of the ladder.

Stepladder stability and overreaching of the user are the major reported hazards of this type product. Early stability research movies of a 6 ft. stepladder test reviewed at the 12th A14 Testing Task Force meeting demonstrated the effect of the man's position on the stability characteristics of the system, and the types of deformation and fractures that could be generated. The prevalent stepladder damage, inward lateral bending of the front rails below the bottom step, occurred when the ladder was tipped over with the user leaving the ladder and then falling back onto the ladder with his impact generating the damage.

Fox[48] studied some aspects of stepladder stability. The ANSI A14 Testing Task Force has performed a wide range of stability tests on stepladders. Included were modifications of the current requirements as well as a series of rather extensive special tests to evaluate different research concepts.

A study[49] indicated that as the applied weight was shifted from a location at the bottom step of the ladder to the ladder top the forces decrease in the front rails, and increase in the rear rails of the stepladder. Similar results were found in later dynamic studies. The data further indicated that the side stability and rear stability of the ladder was drastically reduced as the location of the applied load is raised higher up the ladder and directly onto the ladder top, itself.

Different design approaches to improve stability have been evaluated. The idea of permitting only platform type ladders to be offered for sale was considered with its resulting improvement in stability. However, there were applications where even this design represented significant hazards.

Numerous prototype ladders were constructed enabling the A14 Testing Task Force to evaluate different proposed design solutions. Until we move to an extremely radical design change, the improvements in stability are definitely limited. Field tests still underway indicate mixed comments with respect to the more radical design. They represent solutions which would force a definite change and certain "trade-offs".

Proposals to restrict the user's ability physically to stand on the top step of the stepladder were studied. Likewise the proposal to effectively lower the step pattern by 6 inches was explored. Each of these would effectively cause the user's center of gravity to be shifted downward, and would thereby improve the stability situation. Consumer Sounding Board reaction varied depending upon the knowledge and the viewpoint of the participants. Actual field tests indicated a tendency for users to defeat the intent in their quest to reach the elevation necessary for them to complete the job at hand.

The "Tests of Human Falling from Stepladders"[50] is a comprehensive study of the man:ladder interface. The free fall studies demonstrated that the various types of deformation or fractures often seen in IDIR's were not generated. Overreaching, particularly at the upper step levels, caused the user to fall. Depending upon the surface on which the ladder was positioned, the ladder might slide or tip. To consistently tip the ladder, a system which effectively caused the sudden loss of support in one foot was necessary. The danger of placing a folded stepladder against the wall and working from it was visually demonstrated. At some angles the ladder would literally slide down the wall by its own weight. Videotapes, movies and still photographs were taken of these experiments and will be incorporated into educational materials in the future.

As with extension ladders, there is continuing research being undertaken to determine what might be achievable in the future. Meanwhile, proper ladder

selection and use are the keys to accident reduction.

LADDER TESTS

Snyder[51] discussed standards as they relate to the legal system, and the fact that it is sometimes the "present state of technology which is deficient, not the manufacturer". The State of Washington Appellate Court[52] stated: "Standards were admissible as a sole defense". This case involved the ANSI A14 Portable Metal Standard. Bell[23] discussed the two schools of thought with respect to Illinois Product Liability [53,54]. Thus, the Interagency Task Force[55] concluded that for Illinois "*State-of-the-art* evidence is irrelevant in a strict liability action". The A14 Committee has been generating ladder Standards for guidance since 1922. It will continue to perform its responsibility and leave the legal questions as to their applicability to the Courts.

The basis for A14 Standards, whether they be performance or specification orientated, are performance tests. Due to their volume, it is impossible to discuss or even briefly summarize much of the test work that has been accomplished during the A14 current review. Earlier some of the other considerations were discussed. The current data bank involves over 275 documents, many of which in themselves represent summaries of extensive research and testing. Some examples have been selected and results discussed to illustrate the activities.

Extension Ladder Tests

Fox[56] reported strain measurements for static horizontal bending and dynamic use tests of a Type I 28 ft. aluminum extension ladder. The ladder actually developed higher strain values in the horizontal bending test with a 200 lb. static load than it did in any of the inclined use tests with a 205 lb. dynamic load as seen in Table IV.

His strain measurements of ladders placed at their working angles showed that the strain will vary with the weight of the user, variation of the angle from 75.5°, and the speed of the climber. These types of results have been reported by various authorities.

At no time did Fox's inclined values reach the same strain level as was measured in horizontal bending.

The horizontal bending test is not always the critical performance requirement that defines the design of extension ladder. Certain requirements control with one length of ladder while others become critical for another length. The "column effect" produces increased bending due to extension ladder deflection which is recognized by means of the Deflection Test requirements in the Standards. In the longer length ladders the potential added moment is offset by a reduced dynamic effect due to the greater absorption of energy.

The "Simulated In-Use Inclined Load Test" has been used for years by various manufacturers. In effect it is the true "performance test" of extension ladders as the ladder is placed at the proper use angle and the design or working loads applied to the structure. Objections raised to the Horizontal Bending Test are answered with the Inclined Use Test.

However, the test is much more difficult to perform and is inherently less reproducible as a consequence. While creating little problem with shorter length ladders, the available vertical support structures for longer length ladders are limited. Problems are serious with product 28 ft. and longer. There is a definite safety hazard which must be recognized and resolved when one applies the test load to the ladder. This is of particular significance where there is a test failure or where the loading device is "makeshift" and it, itself, represents a hazard.

Fox[48] proposed testing extension ladders in horizontal bending by applying the load at several locations across the overlap of the fly and base sections. The "reserve capacity" in a metal extension ladder prior to failure based upon ultimate load capacity criteria is presented in Table V. With loading at the center of the overlap, the ladder had an ultimate failure at 250 lbs. versus the Standard's 200 lb. requirement. Inclined, at the normal use angle (75.5°) its ultimate failure occurred at 1100 lbs., while at 60° it was 500 lbs. The ratio of the inclined loading ultimate load capacity to the rated load capacity (200 lbs. for this ladder) was 5.5X at the center and 4.62 - 4.88X at either extreme of the overlap when tested at 75.5°. At 60° the initial ratio is 2.5X at the center, and it varied from 2.12 - 2.25X at the extremes. The intent here is not to imply that the ladder should be used at 60° but rather that they do carry respectable loads at that angle of inclination.

In all of the Fox[48] studies, the only instance where a product failed - even at the 60° angle in dynamic tests - occurred when the material employed in the ladder represented a "flaw". It might also have been termed a "defect" because it did not comply with the material requirements of that particular design and resulted in a failure.

Results from Inclined Use Tests vary as a function of ladder length. The data in Table VI illustrated that at 70.5° (Dewar's alternate angle) ladders were available which met the full test requirements for loadings at 75.5°.

One test[57] took an extension ladder fully extended and set it against a wall at 75.5°. The working or Duty Rating load was applied to the rung at the mid-span of the ladder. A side load perpendicular to the plane of the ladder at the same rung location was applied to determine when the ladder would tip. A 16 ft. Type III Consumer grade ladder with a 200 lb. working load required 30 lbs. of side load to cause the top end to move. The same ladder when physically restrained at the top and bottom ends required 250 lbs. of side load to cause ultimate failure in the side rail. A 28 ft. version required 20 lbs. of side load for end cap movement and 110 lbs. for siderail failure. These values tend to confirm some of the opinions stated during the IDIR analysis.

Another study[58] was performed to evaluate what effect the location of a user has on the force necessary to cause sideways sliding of the top of an extension ladder. The ladder was set up at its normal use angle (75.5°), fully extended, and a 200 lb. load was employed to simulate the user. With the "user" at the third rung from the bottom, the side load was only 4 lbs. while it became 11 lbs. with the "user" on the middle rung.

When the "user" was on the third rung from the top, the force became 22 lbs. If rubber were attached to an end cap in an effort to improve its co-efficient of friction, the sliding force rose to only 33 lbs. The force necessary to maintain the sliding - which is sometimes a measure of the dynamic co-efficient of friction - was 33 lbs. without any additional rubber and 40 lbs. with the added material. These top slip results correlate with Dewar's experience.

The lateral slipping of extension ladders when placed against metal gutters has been a concern. One test[59] determined that the lateral force to cause slippage ranged from 15 - 23 lbs. utilizing a 200 lb. simulated "user" and having the ladder set an the 75.5° angle. The ladder was extended and placed against a metal gutter. The load was located on the rung which was adjacent to the contact point of the upper support on the gutter. The larger lateral force occurred when there were two rungs extended above the gutter and the "user" load was placed on the third rung with its related rail surface making contact with the gutter.

A series of standardized test procedures have now been developed to evaluate end cap slip, rail slip against gutters, and extension ladder foot slip. In the development of the actual test methods, a series of different surfaces were employed in order to evaluate each of their effects upon the test measurements.

Frequently there is concern over the influence of damage due to deformation or distortion of the ladder rails. A special extension ladder test[60] evaluated the effect of deliberately inducing permanent set in the ladder rail. The rail was bent inwards by excessive siderail cantilever bending. The other rail was straight. The ladder was set up at the 75.5° use angle and a step to siderail shear test, which simulates the effect of a user's shoe applying load to the structure, was employed. This load was located on the bottom rung adjacent to the deformed rail. For reference purposes, a ladder without any deformation or distortion was also tested. This unit carried 1400 pounds before failure. In the deformed rail tests the permanent set was varied from 1/16" through 1/4". The failure loads varied from 1225 lbs. down to 900 lbs. This was for a Type III extension ladder with a test load requirement of 800 lbs.

Another series of tests[61] employed 16 ft. Type III extension ladders with unusual damage induced in the rail(s). One ladder had the load applied at the third highest rung. A 1/32" notch was cut into the tension flange of one rail at the second lowest rung in the ladder. The unit was able to carry 850 lbs. before failure at an inclined angle of 75.5°. Another ladder had the load applied at the second lowest rung. The tension flange of one siderail at that location was cut through to the rung and the ladder was set up at 62°25'. The unit carried 1100 lbs. before failure. A third ladder had load applied at the fifth rung from the bottom in the overlap area. Both base section siderails were deformed 3" above the second lowest base rung and the ladder still carried 2550 lbs. before failure. These are just some of the special tests performed to evaluate unique situations.

An analysis of the Fox[48] dynamic data indicated a 100% increase in the static bending stresses as the ladder angle decreased from 75.5° to 60°. At the same time, the dynamic stresses only increased 30 - 40%. Thus, "flatter angles result in less dynamic stress increase"[62].

NBS reports[63,64] discuss several extension ladder tests and various ladder standards as they relate to fire ladders. The reader should be aware that the A14 and NFPA 193 Standards are not equivalent. In fact, they have different objectives.

Stepladder Tests

There has also been concern about the effect on the load capacity of stepladders where deformed rails exist. A 6 ft. Type II stepladder[65] was employed in this series of tests. In the first group a front rail was predamaged. A step to front siderail shear test was employed, again simulating the effect of a user's foot on the bottom-most step. Without any predamage or permanent set, it took 1600 lbs. to cause failure. When the particular front siderail was predamaged by an excessive siderail cantilever load, the step to siderail shear test failures occurred between 1825 - 2300 lbs. for permanent sets of 1/16" through 1/2". At predamage levels of 1", the failure load was 1675 lbs. An equivalent series of tests with the rear rail predamaged resulted in an 1150 lb. failure with no permanent set, and 1100 lbs. with 1" of permanent set. A Type II stepladder, in this particular step to siderail shear test is required to withstand a 900 lb. test load.

Stability tests of stepladders have been performed repeatedly. The location and magnitude of particular loads influence test results. The position and direction of the pulling forces to simulate instability also effect actual measured values. Consequently, a rather thorough study of data is necessary to comprehend what has been done over the years. In one series of tests[49] the side stability on a 6 ft. Type II ladder varied from 18 lbs. with the load on the ladder top; to 40.5 lbs. with the load on the second highest step (4th step from the bottom); to 42.8 lbs. when the load was located on the middle step (3rd step from the bottom). The man's location would alter these values because the user's center of gravity shifts the man:ladder system's center of gravity significantly.

Various Outside Experts provided substantial input on stepladders. Their concerns related principally to certain characteristics of stepladders which none of the existing requirements evaluated specifically. Such terms as "walking", "torsional instability", or "buckling", "racking" and "rail torsion" were typical phrases employed in discussions. Frequently the tests proposed measured characteristics that were quite similar. Often the methods employed were difficult to reproduce by qualified testing personnel, let alone non-specialists. In addition, the co-efficient of variation of the particular methods described were excessive and hence the procedure demanded further study. A wide range of tests evaluating these characteristics were investigated. During the "Human Falls Experiment"[50] particular attention was paid to the movement of the various ladder components in an effort to ensure that we were really evaluating the proper characteristics in the new range of contemplated tests. The proposed Torsional Stability Test, Racking Test and Rail Torsion and Spreader Test do represent advancements in that we are now able to measure these various characteristics effectively.

In one special study early in the development[66], stepladders were set up and the amount of lateral force on rear rail assemblies necessary to produce specific horizontal deflections in the rear assembly were measured for a 6 ft. Type II ladder. One such test showed,

for a 4" deflection, that 5-1/4 lbs. lateral force was necessary. In compression loading, the Type II ladder must sustain 900 lbs. The 6 ft. ladder in compression, even with the 4" lateral displacement, did not fail until loaded to 2375 lbs. at which time the rear rail failed.

One must view the videotapes and motion picture film from the Human Falls Experiment to appreciate how the ladder structure actually reacts. Drastic lateral deflections in the rear rail assemblies did not cause failure. A wide range of tasks that certainly had to be considered reasonable foreseeable misuse did not cause failure.

Many of these tasks did not even result in the user falling from the ladder. Having deliberately stood on the top of a 6 ft. stepladder that had been intentionally failed, I know the amount of effort that was necessary to cause my falling. My body moved in one direction and the reaction forces resulted in the ladder tipping away from me. In this case there was no additional structural damage to the ladder.

In our research we were able to "ride" ladders into very unusual positions without any damage to the product or injury to the experimenter. It did reveal some of the factors that can cause accidents. Just as Dewar firmly established for extension ladders, there are relations between the user's center of gravity and the center of gravity of the stepladder which influence significantly the man:ladder system. Vertical forces available to cause resistance to ladder slip also vary with user elevation.

Data Reduction and Analysis

The Testing Task Force's work has been broken down into special assignments. As a given test method is either reconfirmed or a new procedure adopted, round-robin testing is accomplished. (Recognizing that in many cases the tests themselves are destructive, the contribution by the participants is rather costly.) The data is statistically analyzed. The data is reduced and linear correlations developed. In some situations the relation is between the Ladder Type and the performance characteristic involved. In others, the evaluation is much more complex and might consider length of ladder, ladder Type, and material of construction as separate variables versus the performance characteristic. Once the correlation relationship is developed, then the decision with respect to the requirement limits can be established intelligently. These may frequently represent a higher "level" than the minimum projected by the test data. This judgmental decision is made after the various "trade-offs" are considered.

THE PRODUCT: A REVISED LADDER STANDARD

We have briefly discussed several of the factors that need to be explored, reviewed and evaluated in the course of developing a Standard. In this case, a revision was involved. However, similar experiences were encountered when the ANSI A14.5-1974 Standard, which was the initial issue, was developed.

A working group initiates a "draft". It becomes the basis for discussion with subsequent revisions, deletions and additions. Tests are performed and results evaluated. Requirements are proposed. The impact of these potential requirements are explored to determine their implications to users, producers and other parties at interest.

The various trade-offs are defined. Reactions and responses from different "interests" are solicited and evaluated. Judgments are made. Finally, a proposal is submitted to the Subcommittee and eventually to the Main Committee for letter ballot. In many cases, only with letter balloting do the "bedrock" issues surface that must be resolved for consensus. ANSI requires a Public Comment period which involves their Consumer Council's Standards Screening and Review Committee. Only after all comments are satisfied will ANSI's Board of Standards Review consider the proposal.

The A14 Testing Task Force has anticipated completion of the current project this summer. In August, joint meetings with the A14 Advisory Committee are scheduled. The individual Subcommittees should accomplish their work this fall. If the projected schedule is met, revisions should be issued by ANSI in 1978.

The efforts of the Testing Task Force are the principal resource from which A14 will evolve revised Ladder Standards. The product of the Task Force consists of revised test procedures written up rather explicitly. Included will be the description of the test method; diagrams, as required; proposed limits and the rationale. There are major additions of test methods, a series of tighter limits to existing requirements, and several new limits included in the draft A14 Testing Task Force "work product". Every attempt will be made to ensure that "the Standard can stand on its own feet".

The "state-of-the-art" should be rather apparent as a consequence of this momentous task. Probably as important will be a more precise definition of the "present state of technology" which, in itself, may be the limiting factor on where "state-of-the-art" is today.

The A14 Testing Task Force is proposing ongoing research activities in a number of areas. Hopefully, the results of these efforts will eliminate some of the technology gaps that presently exist. Certainly further work in human factors, dynamics, and slip measurement, coupled with an improved understanding of the man:ladder system from a stability viewpoint, would all be worthwhile.

The steps taken by the American Ladder Institute relative to additional labeling of ladders needs to be evaluated.

The American Ladder Institute:ANSI A14 Educational Project in conjunction with CPSC could be the most significant action resulting from the entire Standards-making activity.

CONCLUSIONS

1. In 80 - 90% of ladder accidents the user appears involved through misuse or improper use. Research indicates that design changes or increases in structural characteristics will NOT in themselves reduce accidents.

2. User awareness of the high hazard potential of ladders coupled with knowledge of the primary and secondary hazards should reduce accidents. The ALI Labeling Program developed in cooperation with CPSC segregated hazards into primary and secondary hazards caused by foreseeable misuse.

The primary hazards are identified on ladders manufactured after April 1, 1976 by labels. In addition, the "Highest Standing Level" which is the maximum level where the user should place his feet is established.

3. Effective user education is necessary. Adequate training of consumers and workers using ladders must be undertaken on a continuing basis. The A14 Standards "Care and Use" section, CPSC's Fact Sheet 56 - Ladders, and other similar publications should be consulted. CIS-12 "Ladders" provides a comprehensive understanding of the consequences of misuse and improper use.

4. Proper ladder selection for the task to be accomplished is important. Labels and other instructions should be read and observed. Instruction labels containing "Care and Use" information conforming to A14 and CIS-12 recommendations have been available for years from certain manufacturers.

5. "Useful Life" of ladders is well below the 20 - 30 years user surveys indicated. Periodic inspection of ladders is needed. Maintenance should be accomplished - or the ladder replaced - to prevent accidents. Ladders have not been designed nor have manufacturers implied that they represent a "lifetime purchase".

6. Dynamic loading tests have been conducted by various manufacturers for many years. The A14 Testing Task Force had numerous dynamic studies performed in addition to those sponsored by CPSC. One current task involves a stepladder cyclic loading program. Cumulative results to date from tests have not justified the concern expressed by certain outside experts.

7. Ultimate load capacity tests which have been performed by manufacturers for years were utilized in this program. Results verify the reserve capacity of these ladder products.

8. The A14 Testing Task Force proposed test requirements represent a significant tightening of performance criteria. The statistical analyses and linear correlations frequently showed correlation co-efficients in excess of 0.90. There are a number of ladder manufacturers who presently meet or exceed the more stringent criteria. A system of conformance grading which evaluates the degree above specification that products represent would reveal this fact.

9. The A14 Testing Task Force employed in its work the CPSC Hazard Analyses, Engineering Studies and Recommendations, NEISS data, In-Depth Investigative Reports (IDIR's), and all suggestions. Consumer input was solicited and the program utilized the ANSI/ASTM/NBS Consumer Sounding Boards extensively. Independent outside technical experts contributed to the knowledge and understanding developed during this program. All meetings were public and publicized through the CPSC Calendar.

10. Basic research studies were implemented in various areas. Certain results have yielded performance test criteria. Other topics are still being evaluated. Included are dynamic foot slip on step/rung surface tests; cyclic loading tests; stability tests and impact of service or usage on ladder performance. A number of other significant research areas would justify study when additional funding support is located.

11. Ladder size or length has a significant influence on performance. The development of criteria needs to consider ladder size, Type, duty rating and construction material.

12. Human factors were considered in both step and extension ladder studies.

13. With regard to extension ladder slip, the user can minimize the hazard by maintaining the recommended 75.5^{o} ladder angle (quarter length rule) and recognize that his "on-ladder" location establishes the effective point when slip might occur.

Slip possibilities significantly increase at or above the mid-point of the ladder's working length.

14. To minimize stepladder instability, don't stand above the Highest Standing Level.

15. Ladder tipping and instability hazards decrease when the user keeps his center of gravity between the ladder rails. Don't overreach!

16. Field trials using specially designed and built prototype experimental stepladders are continuing. The task represents a long term research activity involving user evaluation in order to develop improved safety features.

17. Proper placement, erection and securing of ladders will reduce accidents.

18. The physical condition of the user and his dress are definite accident causation factors.

19. The ANSI A14 Testing Task Force has considered intended use as well as reasonable foreseeable use and misuse. "State of Technology" limitations coupled with basic laws of physics restrict design solutions in certain instances. In these cases education becomes most important.

20. The service capability of a ladder involves several factors perhaps as important as conformance to the ladder "Type" requirement. Features in the design and construction, including workmanship, significantly influence service life and acceptability to the user.

21. The A14 Testing Task Force effort represents a major expenditure (estimates of $300,000 to $500,000 spent by early 1977) on the part of the voluntary standards sector to generate an improved Safety Standard. The contributions of many knowledgeable people and support from their employers are the primary reasons we can discuss facts and results today!

22. Standard Writing Made Easy is a misnomer. To write a Standard requires dedication, hard work, contributions from most - if not all - parties at interest, experienced and knowledgeable experts in the field, willingness to understand the needs of others, ability to recognize the necessity for trade-offs, and a purpose.

TABLE II
BCL SURVEY OF CONSUMER LADDER AGE[27]

Ladder Type	Age, Years	Cumulative % Ladders in Use Wood	Metal
Stepladders	0 - 4.9	20.2%	31.9%
	0 - 9.9	40.6	65.2
	0 - 14.9	62.8	91.6
	0 - 19.9	75.1	95.6
	0 - 24.9	90.3	98.7
Extension Ladders	0 - 4.9	2.1%	31.5%
	0 - 9.9	10.6	69.7
	0 - 14.9	25.4	90.2
	0 - 19.9	53.6	96.5
	0 - 24.9	74.7	99.3

* * * * * * * * * *

TABLE III
CONDITION OF CONSUMERS' LADDERS[27]

Ladder Type	% Considered in Excellent and Good Condition Wood	Metal
Stepladders	63.3%	81.9%
Extension Ladders	74.8%	88.1%

* * * * * * * * * *

TABLE IV
STRAIN MEASUREMENTS FOR STATIC HORIZONTAL BENDING AND DYNAMIC USE TESTS
(Type I Aluminum Extension Ladder)

Test Condition	Test Load	STRAIN (10^4in./in.) 28 Ft. Ladder Fully Extended (25 ft.) Average	Highest Value
Horizontal Bending	200# Static	19.3	20.1
75.5° Inclination	205# Dynamic	12.0	12.8
70° Inclination	205# Dynamic	15.8	17.0
65° Inclination	205# Dynamic	16.4	17.6
60° Inclination	205# Dynamic	18.0	19.6

Source: ANSI A14 Testing Task Force
Document #166
Tables 20, 21

* * * * * * * * * * *

TABLE V
ULTIMATE FAILURE LOADS IN HORIZONTAL BENDING AND INCLINED USE TESTS
(Type III 20 Ft. Aluminum Extension Ladder)

Test Condition	Horizontal Bending	Ladder Inclined at 75.5°	60°
Ultimate Test Load at Center Overlap Rung Location	250#	1100#	500#
Ratio Ultimate Inclined Load to Ultimate Horizontal Bending Load	-	4.40	2.00
Ratio Ultimate Inclined Load to Rated Load Capacity of 200 lbs. for Ladder	-	5.50	2.50

NOTES:
1. Source - ANSI A14 Testing Task Force Document #187.
2. 20 Ft. Extension Ladder has 17 Ft. Working Length and 16 Ft. Horizontal Bending Test test span.
3. Load applied via 3½" wide straps on rung adjacent to both siderails for horizontal bending; equally to both rails via bar through rung for Inclined Load Tests.

* * * * * * * * * *

TABLE VI
ULTIMATE INCLINED USE TEST LOADS
(Type I - Heavy Duty, 250 lb. Duty Rating, Aluminum Extension Ladders)

Size	Working Length	Actual Failure During Inclined Use Test 75.5°	70.5°
16 Ft.	13 Ft.	1350#	1050#
28 Ft.	25 Ft.	1475#	1000#

NOTES:
1. Source - ANSI A14 Testing Task Force Document #70.
2. Failures at reported loads were rung failures. 28 Ft. unit at 70.5° had rail failure at 1300 lbs.
3. Load was applied at centermost rung over central 3½" strap.

* * * * * * * * * *

ACKNOWLEDGMENTS

Thanks are extended to R. D. Werner Co., Inc. for permission to publish, and to the A14 Standards Committee for providing the Standards-writing opportunity. The author acknowledges the major contributions of Harold W. Stillman and Richard L. Werner, Chairman and Secretary, respectively, of the A14 Testing Task Force, as well as all the members. The untiring efforts of Thomas F. Bresnahan, Secretary, and the encouragement of Gordon B. Lemke, Chairman of ANSI A14, are also acknowledged. The contributions of Langston F. Bate, Jr., of CPSC, are appreciated.

The views stated are the author's personally and not necessarily those of R. D. Werner Co., Inc. or the A14 Standards Committee.

BIBLIOGRAPHY

1. ANSI A14.1-1975 - Safety Standard for Portable Wood Ladders.
2. ANSI A14.2-1972 - Safety Standard for Portable Metal Ladders.
3. ANSI A14.5-1974 - Safety Requirements for Portable Reinforced Plastic Ladders.
4. U. S. Department of Commerce, Briefing Report - Interagency Task Force on Product Liability , January 1, 1977.
5. California Citizens' Commission on Tort Reform, Report to the. Products Liability, Oct., 1976.
6. Aluminum and Magnesium Step and Extension Ladders, Denial of Petition, Federal Register 41 FR 52100, November 26, 1976.
7. Weinstein, A. S. and Frank, J. C. "The Ladder Standard: How Successful the Climb?" ASTM E40 Symposium, May 5, 1977, Technical Standards in Products Liability Litigation.
8. Werner, R. I., et al. "The ANSI A14 Testing Task Force Reviews the Technical Paper 'The Ladder Standard: How Successful the Climb?'" ASTM E40 Symposium, May 5, 1977, Technical Standards in Products Liability Litigation.
9. International Occupational Safety and Health Information Centre (CIS), CIS-12 "Ladders", International Labour Office, CH 1211, Geneva 22, Switzerland, December, 1966.
10. Fandey, J. E., CPSC, "Briefing Paper on a Petition from Frederick Saphra, P.E.", (CP-75-9)"Request Standard Development for Aluminum and Magnisium Ladders", OSCA, 24 Aug. 1976.
11. U. S. Consumer Product Safety Commission, "Product Profile - Ladders", Oct., 1976.
12. Consumer Product Safety Commission, "NEISS News", published periodically.
13. CPSC "Consumer Product Safety Index", Feb. 7, 1977.
14. CPSC "Ladder Test Design and Evaluation", April 28, 1977, CPSC-P-77-826.
15. See Ref. 10 Tab. I "NBS In-Depth Investigative Report". The copy in ref. 10 represents the initial draft. The finalized corrected draft contains analysis of 225 reports with various other changes and should be employed.
16. ANSI A14 Ladder Standards Committee, "An Evaluation of CPSC - IDIR's by ANSI A14 Testing Task Force and American Ladder Institute", conducted 6/21-23/76.
17. British Post Office, Engineering Safety Officer, "Survey of Accidents Caused by Slips and Falls from Poles and Ladders - 1971", TD8 Branch Investigative Report #206.
18. Webster's New World Dictionary, 2nd Edition, 1974, p. 1507.
19. Lowrance, William, Of Acceptable Risk - Science and the Determination of Safety, Wm. Kaufman, Inc. Los Altos, Calif.
20. ibid. p. 95.
21. ibid. p. 87.
22. Genaust v. Illinois Power Co., 62 Ill. 2nd 456,471,343. N.E. 2d. 465 (1976).
23. Bell, John W., "Averting a Crisis in Products Liability: An Evolutionary Process of Socio-economic Justice", Illinois Bar Journal, June, 1977, pp. 640-648.
24. Hagglund, George, "OSHA - Causes of Injury in Industry - The 'Unsafe Act' Theory", Univ. of Wisconsin, Extension School for Workers, Madison, Wisconsin, July, 1976.
25. Heinrich, H. W., Industrial Accident Prevention: A Scientific Approach, 4th Ed. N.Y., McGraw Hill Book Company, 1959.
26. Employers Insurance of Wausau, "Getting to the Root of Ladder Accidents", November, 1973.
27. Otis, J. L., et al., Battelle Columbus Laboratory, "Research Report on Estimated Numbers in Use and Average Life for Rung Ladders, Stepladders and Step Stools Used by Consumers to CPSC", April 17, 1975; CPSC-C-74-195, Task 8952.
28. ANSI A14 Testing Task Force, "Ladder Cyclic Loading Equivalency", Document #73.
29. ANSI A14 Testing Task Force, "Cyclic Stepladder Loading Tests", Document #6.
30. ANSI A14 Testing Task Force, "Special Inclined Use Test of Extension Ladder with Load Reversal", Document #15.
31. Werren, F., Allowable Bending Stresses of Wood for Use in Portable Wood Ladders, U.S.D.A. Forest Service General Technical Report, FPL-5, 1975, Forest Products Laboratory, Madison, Wis.
32. Winnett v. Winnett, 57 Ill.2d. 7,12,13,310 N.E. 2d. I (Sup. Ct. 1974).
33. U. S. Consumer Product Safety Commission, "Fact Sheet No. 56: Ladders".
34. National Bureau of Standards Report, "A Review of Safety Related Patents for Portable Ladders", CPSC Project 131.
35. Hepburn, H. A., "Portable Ladders: Part II - Footing the Ladders - Theory and Practice", British Journal of Industrial Safety, 4, No. 47, pp. 161-163, 1958.
36. Hepburn, H. A., "Portable Ladders: Part III - Ladder Loading", British Journal Industrial Safety, 4, No. 49, pp. 205-209, 1958.
37. Dewar, M. E., "Investigations of Factors Contributing to Ladder Accidents. . Friction at the Foot of the Ladder", Issue 2, April, 1973, Human Biomechanics Laboratory, National Institute for Medical Research, London, England.
38. Dewar, M. E., "Investigations of Factors Contributing to Ladder Accidents. 2. Leaning Sideways at the Top of the Ladder", Issue 1, February, 1974, Human Biomechanics Laboratory, National Institute for Medical Research, London, England.
39. Dewar, M. E., "Investigations of Factors Contributing to Ladder Accidents - 3. Body Movements During Climbing". Issue 1, April, 1975, Human Biomechanics Laboratory, National Institute for Medical Research.
40. Dewar, M. E., "Body Movements in Climbing a Ladder", Ergonomics, 1977, Vol. 20, No. 1, pp. 67-86.
41. Best, F. L., "Anti-Slipping Devices for Ladders", C.N. Branch Investigation Report No. 138, Sept. 1964, British Post Office, Telecommunications Headquarters.
42. Binchel, D. R., "Summary of Additional Investigation of Anti-Slipping Devices and Materials for Ladders", June, 1969, No. TD8.7.3, British Post Office Telecommunications Headquarters.

43. ANSI A14 Testing Task Force, "Special Extension Ladder Slip Resistance Tests", Documents 111,112.
44. Fox, R., "Case Western Reserve University - Co-Efficient of Friction - Extension Ladder", A14 Testing Task Force Document #165.
45. Hepburn, H. A., "Portable Ladders, Part I: The Quarter-Length Rule". British Journal Industrial Safety, 4, No. 46. pp. 115-158.
46. International Occupational Safety and Health Inf. Ctr. Regulation 211, "Equipment and Tools", p. 403, para. 22 of Model Code of Safety Regulations for Industrial Establishments for the Guidance of Governments and Industry, International Labour Office, Geneva, 1949.
47. British Post Office, "Safe Use of Ladders", Telecommunications Instruction No. M4 E0091, Sept. 1974, Telecommunications Headquarters.
48. Fox, R., "Report on Dynamic Testing of Ladders, Contract CPSC-C-76-0052, at Case Western Reserve University", 1976. CPSC. (A14 TTF Document #166.)
49. ANSI A14 Testing Task Force "Special 6 ft. Stepladder Tests", Document #2.
50. ANSI A14 Testing Task Force "Tests of Human Falling from Stepladders", November 4, 1976, Document #186.
51. Snyder, D. J. Jr., "Perspectives of the Legal Systems, ASME Technical Paper 77-DE-22 (Jan. 31, 1977).
52. Nordstrom vs. White Metal, 453 Pacific 1st Dist., 1964, 2nd, 619, 1969.
53. Suvada v. White Motor Company, 51 Ill. Appl. 2d 318,201 N.E. 2d 313. (1st Dist., 1964), and Suvada v. White Motor Company 32 Ill. 2d., 612,210, N.E. 2d 182 (1965).
54. Cunningham, v. MacNeal Memorial Hospital, 47 Ill. 2d 443, 266 N.E. 2d 897 (1970).
55. Federal Interagency Task Force on Product Liability, Legal Study, Vol. III, p. 43. January, 1977, PB 263 601.
56. Fox, R., "Report on Dynamic Tests of Ladders", ANSI A14 Testing Task Force Document #165, Tables 20,21.
57. ANSI A14 Testing Task Force "Special Extension Ladder Inclined Load Test with Side Loading", Document #69.
58. ANSI A14 Testing Task Force "Extension Ladder Stability Testing", Document #23.
59. ANSI A14 Testing Task Force, "Extension Ladder Lateral Slip Resistance Test Against Gutter", Document #146.
60. ANSI A14 Testing Task Force, "Special Extension Ladder Test with Predamaged Rail", Document #110.
61. ANSI A14 Testing Task Force, "Extension Ladder Ultimate Load Capacity Tests", Document #5.
62. ANSI A14 Testing Task Force, "An Evaluation of the CWRU 'Report on the Dynamic Testing of Ladders'", by ANSI A14 TTF, May 31, 1977, Document #267.
63. Robinson, E., "Mechanical Tests and Analysis of Fire Department Ground Ladders", NBS Report 10 474, August, 1971.
64. Utech, H., "Fire Department Ground Ladders - Results of a Preliminary Study", NBS Technical Note 833, July, 1974.
65. ANSI A14 Testing Task Force, "Special Stepladder Test with Predamaged Rail", Document #109.
66. ANSI A14 Testing Task Force, "Special Stepladder Test with 1" - 4" Induced Lateral Displacement of Rear Rail Assemblies", Document #72.

Article from
The Wall Street Journal
Issue of August 11, 1977

Step by Step

Setting Safety Rules For Products Proves Costly and Complicated

Ladder Makers and U.S. Body Negotiate for Two Years, Debate Costs of Redesign

Protecting Little Old Ladies

By FREDERICK C. KLEIN
Staff Reporter of THE WALL STREET JOURNAL

"We argued back and forth for more than two hours about a 15-word section of our safety code. When the meeting was done I asked myself, 'Am I in the ladder business, or am I building rocket ships to go to the moon?' "

Robert Werner, vice president of R. D. Werner Co., Greenville, Pa., is, indeed, in the business of making aluminum ladders, but his momentary disorientation perhaps was understandable. For the past two years he has spent much of his time helping frame safety rules for his industry's products that will meet the approval of the four-year-old U.S. Consumer Product Safety Commission (CPSC).

Ladder makers and officials of the federal agency agree that the rule-making process has been time-consuming, costly, sometimes acrimonious and often bewildering. Committees of government and industry executives and other interested parties have met some 50 times, spent more than $700,000 and accumulated a mound of minutes, reports and studies that fill a good-sized filing cabinet. And the whole thing still has at least another year to run.

Series of Compromises

Both the industry and the CPSC also agree that the standards that will emerge from all of this will represent a series of compromises between production costs and safety that will satisfy neither of them completely.

"We've found that when we deal with a product that's at all complex—like ladders—the best we can hope for is something that will make everyone a little unhappy," says Michael Brown, a Texas lawyer who is the CPSC's acting executive director. "Anyone who expects more isn't being realistic."

A look at the ladder makers' experiences in setting safety rules is instructive because the process will involve numerous other industries in the years ahead. The CPSC, established in 1973 to protect Americans from the hazards associated with things they buy for home or recreational use, has jurisdiction over 10,000 to 12,000 product lines.

So far, the agency only has scratched the surface. It has supervised the drawing up of rules governing the manufacture of only about 50 products, ranging from bicycles to aspirin bottles.

It's likely that this pace will increase in the near future, however. The CPSC is pursuing new safety standards for 46 more products, and it has received petitions asking that it look at another 130 or so with an eye towards future action.

The Clear Hazards

These products, of course, vary widely in danger and complexity, so the CPSC can follow any of several courses in regulating them. The simplest involves the quick removal from the market of items judged to present a clear hazard to users. That's what the agency has done with some flammable fabrics and a number of children's toys.

Mostly, though, figuring out why a product is dangerous and what can be done about it is a complicated matter, and so is the rule-making process. In such cases, the agency can either contract with an independent testing organization to draw up "mandatory" safety standards, or turn the process over to a group that will include the industry concerned on a "voluntary" basis.

The choice between mandatory and voluntary rule-making is that of the industry as well as the CPSC. When a safety code is formulated on a voluntary basis, the industry pays most of the bills but is able to participate directly in writing the safety standards that will affect it.

The CPSC greatly favors the voluntary approach, even though it has been criticized by consumer advocates. "Our staff is small (126 full-time professionals) and so is our budget ($40 million annually)," Mr. Brown points out. "Getting an industry involved makes our resources go farther, and I think it also can lead to greater compliance with the rules that result."

No Sitting Back

The voluntary course was chosen by the ladder makers and most of the other manufacturers whose products have come under CPSC scrutiny. "We could have sat back and let the government do it and then gone to court if we didn't like what came out, but we figured we'd better get in right away," explains William Feder, executive director of the American Ladder Institute (ALI), a trade association whose members include 53 of the 75 or so U.S. firms that make the product. He adds: "It's been a frustrating business, but might have been worse the other way."

Ladder safety became a concern of the CPSC beginning in November 1974, when Frederick Saphra, a New York engineer, filed a petition before the CPSC claiming that aluminum stepladders—the type of ladder most often owned by householders—were "grossly inadequate" to meet the requirements of ordinary use. That's the way all products come before the agency; anyone can ask that it investigate any consumer item.

The agency decided to pursue the matter because it knew well that a lot of people were getting hurt falling off ladders. It surveys injuries treated by hospital emergency rooms around the country, and in fiscal 1975, the latest year for which published figures are available, ladder accidents ranked 22nd among the 369 products monitored. The CPSC estimates that more than 200,000 Americans are hurt in ladder mishaps each year, and that about 80,000 of the injuries are serious enough to require hospital treatment.

This was no news to the ladder makers, who have been a major target of product liability law suits over the past several years. The ALI says that since 1972, members' liability insurance rates have quadrupled, and that insurance ranks behind only materials and labor as a cost to the industry.

When the industry volunteered to cooperate in the standards-setting process, the CPSC turned the matter over to a committee of the American National Standards Institute (ANSI), a private, non-profit body that oversees the making of specifications and safety rules for most products made in the U.S. The committee, like most operated under ANSI auspices, includes not only manufacturers of the product involved, but also representatives of insurance companies, suppliers of raw materials (in this case wood and aluminum), retailers, labor unions, industrial customers and departments of the federal government. In addition, ANSI maintains nine consumer panels around the country, whose opinions have been solicited at various stages of the standards-writing process.

ANSI committees have been writing standards and specifications for ladders since 1923; its rules—updated many times over the years—cover wood, metal and plastic types, and now run to almost 80 pages. But the involvement of the CPSC as monitor of the current process has made it the most thorough and searching ever.

Few aspects of the committee's work have proceeded without argument, with the industry asserting that the vast majority of ladder mishaps are the fault of the user, not the ladder—and warning that changes in design will increase product cost without eliminating many accidents. The government concurs about negligent users, but contends that design changes might help eliminate "reasonable, foreseeable" misuse.

"There's no doubt that no matter what we do, people will continue to do stupid things on ladders and get hurt," says Langston Bate Jr., the CPSC engineer who is overseeing the ANSI safety panel's work. "We'd just like to see ladders built so it will be harder for people to foul up on them."

Complicating the issue is a lack of independent research on this basic household product (a problem with almost every product under consideration). New data gathered by the CPSC seems to have served chiefly to stir up further argument. One survey, for instance, suggested that making

stepladder legs stiffer would make them less likely to collapse in use, but the ANSI panel also heard testimony that this would exacerbate the problem of ladders "walking" on uneven surfaces.

Even where there has been agreement on accident causes, there has been disagreement over remedies. If an extension ladder is made stronger, will it only encourage people to use it at unsafe angles? And questions of cost versus safety have impinged constantly. Will added bracings on extension ladders, and wider bottoms, make the products heavier, harder to store and more costly, thus discouraging their use?

"We're worried about the 86-year-old widow who lives alone," asserts Lewis Berger, president of Louisville Ladder Co., a division of Emerson Electric Co. "If you make a ladder too difficult for her to haul around, she'll use a chair or a table instead, and they're not built for climbing." (CPSC figures show more accidents involving chairs and tables than ladders.)

The standards-setting process for ladders still has a year or so to go, but some safety moves already have resulted. Many ladders now sport stickers illustrating how they should be set up and warning against use of the top two rungs. Even such limited moves, the makers say, add about 75 cents to the price, a 3% increase on a typical five-foot aluminum ladder selling for $22.

Other likely safety changes may cost more—10% to 15%, says the CPSC, with the makers warning that the figure could be 20%. These include the use of slip-resistant materials for stepladder feet, somewhat wider stepladder bases and more bracing all around.

Such increases could shake up the $150 million dollar a year ladder industry, which has about 10 large manufacturers and 60 or so smaller regional producers. "The big makers will be able to absorb the boosts or pass them along more easily than the smaller ones," says Alder Cikra, a sales official of Keller Industries Inc., a Miami, Fla., ladder maker. "I think we'll see some small firms go out of business."

The effects on ladder safety and manufacturers' rising insurance bills aren't yet discernible. What is certain is that the new rules initially will bear out Mr. Brown's observation that all participants emerge slightly unhappy.

"The new rules will be better than nothing, but that's about it," says Mr. Saphra, the engineer whose petition set the whole thing in motion. "Involving the manufacturers in the process rules out any fundamental changes."

And Charles Howard, president of a ladder company based in Kent, Wash., says, "The new rules may help us defend ourselves in court, but maybe they won't. If someone is hurt on an older ladder, his lawyer will be after us to explain why we didn't make the changes sooner."

INSTRUCTOR'S NOTES

Further comments of possible interest are quoted below in an excerpt of a letter from Mr. Robert I. Werner to C. O. Smith.

> Part of the "discussion" between Professor Weinstein and myself related to which standards are applicable and who makes the determination as to whether a specific standard addresses a specific product. We saw in the absence of more definitive performance criteria in the Fire Ladder Standard a move to utilize another standard that was not intended for that application. Professor Weinstein was in part attempting to convey his concepts of "standards of performance" as well as his thoughts concerning "standards for performance."
>
> One of the difficulties that we haven't yet clarified is the question as to what is a better or safer design, as well as what is to be considered a minimal increase in cost of the product.
>
> Lowrance in "Of Acceptable Risk" pointed out: "Safety is the degree to which risks are judged acceptable." What may be "safe" to a "poor" man may be unacceptable to his "rich" uncle.
>
> Your explanation of the ASTM philosophy requiring agreement of all concerned parties is not totally valid. ASTM requires "concensus." That does not mean 100% agreement. It also doesn't mean that the standard will represent the least common denominator in order to obtain a resolution between the interested parties.
>
> In 1979, at the National Safety Congress, I presented a paper which spoke to some degree about 'standards for standards-makers'. This concept had been proposed earlier and very succinctly defined some of the responsibilities that those who write standards have.
>
> I am not sure whether its inclusion would magnify the work of your students.
>
> Moving on to your concluding remarks in Part A, the last sentence is in part describing one of the problems that got some of us involved in the discussion with Professor Weinstein. Mr. Samuel Cramer and myself are volunteers. Neither one of us at the time were chairmen of our respective committees. The NFPA activity, as well as the A14 activity, developed a collective response which was then reworked and presented at the meeting. Each of us happened to be the individual in our standards activity that was selected as the representative.
>
> If you wish to help the student comprehend more of this discussion, then perhaps he or she must gain some insight into the purpose of the particular standards. The ladder standards might well be used as an example in this situation. We have design requirements and we have performance requirements. We have design verification tests, and we have in-service tests. A standard built upon design requirements is different than one created utilizing performance requirements. This is a subtlety which most people don't appreciate.

The various types of tests have different objectives. A design verification test may be performed at the point when a product is designed and never repeated. An in-service test may evaluate the product and determine its suitability for continual use, but tell you little about its ultimate performance capability. A quality control or quality assurance test may be utilized in the manufacturing plant to ensure that the product being produced complies with the engineering requirements of the producer. It may not in itself be a design verification test, at all. It may have only an indirect correlation to design verification.

In the creation of a standard we can expand from this point on for thousands of words attempting to describe the different concepts utilized in standards. This is one reason why ASTM has recently expanded their scope significantly.

Much of what I have just described is covered in the 79th National Safety Congress paper entitled: "Standards for Safety -- Cure-All or Curse?" This was presented last October and is enclosed. I did not either solicit the speaking engagement or the title. The Product Safety Committee wished to develop a dialogue illustrating the different points of view in this area.

The two publications to which Mr. Werner referred are:

Lowrance, W. E., "Of Acceptable Risk," Los Altos, CA, William Kaufman, Inc., 1976.

Werner, R. E., "Standards for Safety -- Cure-All or Curse?" 79th National Safety Congress, Product Safety Committee, Industrial Conference, Session 5 - "Product Safety is Not a Mystery" 16 October 1979.

Both are interesting reading, especially Lowrance.